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RESEARCH MEMORANDUM

AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63°.-SUBSONIC MACH AND REYNOLDS NUMBER EFFECTS ON THE CHARACTERISTICS OF THE WING AND ON THE EFFECTIVENESS OF AN ELEVON

By Robert M. Reynolds and Donald W. Smith

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63°.— SUBSONIC MACH AND REYNOLDS NUMBER EFFECTS ON THE CHARACTERISTICS OF THE WING AND ON THE EFFECTIVENESS OF AN ELEVON

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SUMMARY

A wind-tunnel investigation has been made of a semispan model of a wing swept back 63° having an aspect ratio of 3.5 and a taper ratio (tip chord/root chord) of 0.25. These tests were conducted to evaluate the effects of Reynolds number and Mach number on the aerodynamic characteristics of the wing. Included in the investigation were measurements of the effectiveness of an elevon used as a longitudinal control.

The aerodynamic center of the wing shifted rearward near a lift coefficient of 0.2; whereas above a lift coefficient of approximately 0.4 there was an abrupt forward shift of the aerodynamic center.

Increase of the Mach number from 0.180 to 0.925 at a constant Reynolds number of 3.55 million resulted in a gradual increase of the lift-curve slope at zero lift from 0.043 to 0.048 per degree, a rearward shift of the aerodynamic center at zero lift from 42.4 percent to 44.6 percent of the mean aerodynamic chord, and a decrease of the maximum lift-to-drag ratio from 18.0 to 14.7. The elevon pitch effectiveness (rate of change of pitching-moment coefficient per degree of elevon deflection) had a value of −0.0053, and was not appreciably changed by varying the Mach number from 0.60 to 0.90 at a constant Reynolds number of 2.26 million.

An increase of Reynolds number from 4.11 to 9.85 at an approximately constant Mach number and at a constant dynamic pressure of 50 pounds per square foot caused a reduction of the lift-curve slope from 0.045 to 0.042, and an increase of the maximum lift-to-drag ratio from 17.7 to 20.6. There was little shift of the aerodynamic

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center at zero lift from 42.4 percent of the mean aerodynamic chord. The elevon effectiveness was little affected by changes in the Reynolds number.

INTRODUCTION

Recent developments extending the theory of supersonic flow to the analysis of swept wings of finite aspect ratio (reference 1) have indicated that efficient flight at Mach numbers up to 1.5 may be achieved by the use of a large sweepback angle together with the highest possible aspect ratio.

A wing designed according to the indications of reference 1 is being investigated extensively at the Ames Aeronautical Laboratory to evaluate its behavior over a wide range of Mach and Reynolds numbers, both alone and in the presence of a slender fuselage.

The series of tests performed in the 12-foot pressure wind tunnel and reported herein is part of a coordinated program aimed at the ultimate development of a configuration adaptable to efficient, economical flight at Mach numbers up to 1.5. This report presents the subsonic aerodynamic characteristics of a semispan model of a wing swept back 63° as influenced by the independent variation of Mach and Reynolds numbers. Also included are data on the effectiveness of a constant-chord elevon.

SYMBOLS

The following symbols are used in this report:

C_L lift coefficient $\left(\frac{\text{lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{drag}}{qS}\right)$

C_m pitching-moment coefficient about quarter-chord point of the wing mean aerodynamic chord $\left(\frac{\text{pitching moment}}{qS\bar{c}}\right)$

α angle of attack of wing chord, degrees

δ_e angle between wing chord and elevon chord, measured in a plane perpendicular to the elevon hinge line, positive for downward deflection with respect to the wing, degrees

$C_{L_{\delta_e}}$ elevon lift-effectiveness parameter $\left(\frac{\partial C_L}{\partial \delta_e}\right)_{\alpha = 0^\circ}$, per degree

$C_{m_{\delta_e}}$ elevon pitch-effectiveness parameter $\left(\frac{\partial C_m}{\partial \delta_e}\right)_{\alpha = 0^\circ}$, per degree

M Mach number $\left(\frac{V}{a}\right)$

R Reynolds number $\left(\frac{\rho V \bar{c}}{\mu}\right)$

q dynamic pressure $\left(\frac{\rho V^2}{2}\right)$, pounds per square foot

V airspeed, feet per second

ρ mass density of air, slugs per cubic foot

μ viscosity of air, slugs per foot-second

a speed of sound, feet per second

S wing area, square feet

$\bar{c}$ chord through the centroid of the plan view of the semispan wing, mean aerodynamic chord (M.A.C.), feet

c local wing chord, feet

MODEL

The semispan model tested had its leading edge swept back 63°, an aspect ratio of 3.5 based on the full span, a taper ratio of one to four, zero twist, and the NACA 64A006 low-drag wing section (reference 2) parallel to the stream direction. Dimensions of the model are shown in figure 1. The wing was constructed of laminated mahogany secured to a solid steel spar.

Also shown in figure 1 are the dimensions of the constant-chord elevon. The elevon extended over the outboard 50 percent of the wing span, and its area aft of the hinge line was 12.5 percent of the total wing area. The elevon was attached to the wing by three clamp-type hinges; no provision was made for measurement of hinge moments. The unsealed nose gap was 0.082 inch, constant across the span.

The model was also tested with 1/2-inch-wide roughness strips made up of number 60 carborundum particles imbedded in rubber cement, on the upper and lower wing surfaces so that the leading edge of the strips coincided with the 3-percent-chord station of the wing.

The semispan model was mounted vertically in the wind tunnel, with the floor of the tunnel serving as a reflection plane. Photographs of the model installation are shown in figure 2. The turntable upon which the model was mounted and the turntable cover plates which were exposed to the air stream were connected directly to the force-measuring apparatus. The small gaps between the spar of the model and the turntable cover plates were not sealed. Where the model extended beyond the turntable, the gap between the model and the tunnel floor varied from a minimum of 0.010 inch to about 0.200 inch. No attempt was made to remove the tunnel-wall boundary layer which, at the location of the model, had a displacement thickness of 0.5 inch.

CORRECTIONS TO DATA

The available theoretical developments by which corrections for tunnel-wall interference are normally computed do not lend themselves to the analysis of a highly swept-back semispan wing mounted on a flat of a modified circular test section. As a reasonable estimate, however, approximate tunnel-wall corrections calculated by the method of reference 3 have been applied to the data presented in this report. In order to use this method, the flat on which the model was mounted was treated as a reflection plane and a nominal tunnel diameter was assumed, the square of which equaled $4/\pi$ times the test-section area. A spanwise load distribution computed by the simplified Weissinger method presented in reference 4 was used in the analysis, but no further means of accounting for the large sweepback was used. The corrections added were:

$$\Delta\alpha = 0.93\ C_L$$

$$\Delta C_D = 0.013\ {C_L}^2$$

No tunnel-wall corrections have been applied to the pitching-moment coefficients, but they are believed to be small.

Although the existing theoretical treatment of blockage corrections for closed-throat wind tunnels is strictly applicable only to full-span models located centrally in the tunnel and does not allow for large angles of sweep, the method of reference 5 has been used as a reasonable means of estimating the constriction effects. The magnitude of the corrections applied to the Mach number and dynamic pressure is illustrated in the following table:

Corrected Mach number	Uncorrected Mach number	Corrected q / Uncorrected q
0.925	0.907	1.020
.900	.886	1.016
.850	.842	1.011
.800	.795	1.008
.700	.697	1.005
.600	.598	1.004
.500	.499	1.003

Tare corrections for the air forces exerted on the exposed surface of the turntable have been applied to the drag data. Over the range of test Reynolds numbers of 2 to 10 million, the tare drag coefficient varied from 0.0021 to 0.0018. No attempt was made to evaluate the possible interference effects between the model and the turntable or the effect of the gap between the turntable and the tunnel wall.

TESTS

Lift, drag, and pitching-moment data have been obtained for the model under the conditions listed in table I.

Reynolds numbers of 2.26 and 3.55 million were approximately the lowest and highest attainable with this model at high Mach numbers, being limited in the first case by the minimum pressure to which the tunnel could be evacuated (one-sixth of atmospheric pressure), and in the second case by the available power of the tunnel-drive system. With a tunnel pressure of 6 atmospheres, the highest Reynolds number attainable at a dynamic pressure of 50 pounds per square foot was 9.85 million.

The maximum angle-of-attack range permitted by the limits of rotation of the turntable was -10° to 30°, but in most cases the structural capacity of the model, model vibration, or tunnel-power limitations restricted the angle-of-attack range to -10° to 20°.

Data were obtained for elevon angles from 5° to -40°. At high Mach numbers, this range was further restricted to 5° to -20° because of structural limitations of the model.

RESULTS AND DISCUSSION

Characteristics of the Wing with the Elevon Undeflected

General considerations.– Before discussing in detail the effects of compressibility and scale, it is desirable to point out some of the characteristics of the wing attributable to the particular combination of sweepback and aspect ratio of the model.

Typical variations of the angle of attack, drag coefficient, and pitching-moment coefficient with lift coefficient are shown in figures 3 and 4. A study of these figures reveals the following changes in the trends of the coefficients occurring simultaneously at lift coefficients near 0.2: (1) There is a perceptible increase in the slope of the lift curve; (2) there is a sharp increase in the rate of change of drag with lift; and (3) there is a moderately abrupt rearward shift of the aerodynamic center. In reference 6, this nonlinear behavior of the characteristics is attributed to separation from the airfoil leading edge, with a consequent loss of leading-edge suction and a rapid increase in drag. The 0.2 value of the lift coefficient at which the effects of separation appear, as shown in reference 6, agrees with the indications of oblique-wing theory which predicts this behavior at a lift coefficient equivalent to the section maximum lift coefficient reduced by the square of the cosine of the sweep angle.

With regard to longitudinal stability, the data indicate a behavior typical of highly swept wings and already reported extensively elsewhere (e.g., reference 7). This behavior, illustrated in figures 3(c) and 4(c), is the forward shift of the aerodynamic center which in this case occurs at lift coefficients of the order of 0.4. As discussed in reference 7, this longitudinal instability is primarily dependent upon the particular combination of sweep angle and aspect ratio.

Also of interest are the drag data of figures 3(b) and 4(b), which show the influence of the low-drag wing section between lift coefficients of –0.1 to 0.1.

Effect of Mach number.– Data for Reynolds numbers of 2.35 and 3.55 million and Mach numbers from 0.160 to 0.925 are presented in figures 3 and 4, and the effects of Mach number are summarized in figures 5 to 8.

The data show no abrupt changes with increasing Mach number.

In figures 3(c) and 4(c), it is of interest to note that, as the Mach number is increased, the change to a positive variation of pitching-moment coefficient with lift coefficient does not occur as rapidly as at the low Mach number, but takes place over an increasingly wide range of lift coefficients.

In figure 5, are shown the lift, drag, and pitching-moment coefficients as a function of Mach number. It will be seen that there is a gradual increase of the lift coefficients at constant angles of attack with increasing Mach number. The general trend is for the drag coefficient to increase with increasing Mach number over the range of lift coefficients plotted; however, there is a decrease of the drag coefficient between Mach numbers of 0.750 to 0.925 for lift coefficients of 0.35 and 0.4. At lift coefficients less than 0.25, increasing Mach number caused little change in the pitching-moment coefficients; however, at the higher lift coefficients, the pitching-moment coefficients became less negative as the Mach number was increased.

The effect of compressibility on the variation of lift-to-drag ratio with lift coefficient is shown in figure 6. It is evident that there is a considerable decrease in the value of the maximum lift-to-drag ratio with increasing Mach number.

In figures 7 and 8, are summarized the variations with Mach number of the lift-curve slope at zero lift, minimum drag coefficient, aerodynamic center at zero lift, maximum lift-to-drag ratio, and the lift coefficient for maximum lift-to-drag ratio. Increasing the Mach number from 0.180 to 0.925 resulted in a gradual increase of the lift-curve slope at zero lift from 0.043 to 0.048 per degree, an increase of the minimum drag coefficient from 0.0040 to 0.0052 ($R = 3.55$ million), a rearward shift of the aerodynamic center at zero lift from 42.4 to 44.6 percent of the mean aerodynamic chord, and a decrease of the maximum lift-to-drag ratio from 18 to 14.7 ($R = 3.55$ million). The lift coefficient at which the maximum lift-to-drag ratio was attained did not vary with Mach number.

The early increase of minimum drag beginning at a Mach number of 0.4, as shown in figure 7, was not anticipated for such a highly swept wing. As the Mach number increased, the drag coefficient may have been influenced by such factors as air leakage through the gap between the turntable and the tunnel floor and interference drag between the model and the turntable.

Effect of Reynolds number.– Examination of figures 5 and 6 indicates that differences in the wing characteristics due to a change in the test Reynolds number from 2.35 to 3.55 million are most apparent at the lower Mach numbers and at lift coefficients greater than 0.2. This effect of compressibility on the scale effects may be due to stabilization of the boundary layer as a result of aerodynamic heating or may be due to an increased wind-tunnel turbulence at the higher test speeds. At the lower Mach numbers, the following effects were noted with an increase in Reynolds number from 2.35 to 3.55 million (fig.5): (1) There is a progressive loss of lift with increasing angle of attack; (2) there is a progressive reduction of drag coefficient with increasing lift coefficient; and (3) there are changes in the measured pitching-moment coefficients. The increase in Reynolds number improved the lift-to-drag ratio as shown in figures 6 and 8.

Lift, drag, and pitching-moment data for the wing at Reynolds numbers of 2.35, 4.10, 7.40, and 10.30 million for a constant Mach number of 0.180 are compared in figure 9. Increase of the Reynolds number may be seen to have the effects discussed in the previous paragraph. More clearly shown in this figure, however, is the effect of increasing Reynolds number in extending the linear variation of the pitching-moment coefficient with the lift coefficient to higher lift coefficients. Whereas the tests at a Reynolds number of 2.35 million indicate separation beginning at a lift coefficient of about 0.20, for Reynolds numbers of 4.10, 7.40, and 10.30 million, the separation is delayed progressively to lift coefficients of approximately 0.25, 0.30, and 0.35, respectively.

Because of its particular conformation of sweepback, aspect ratio, and thin wing section, the model was susceptible to considerable bending under lifting loads. Since the magnitude of the deflection is directly proportional to the dynamic pressure, it was thought advisable to vary the Reynolds number while keeping the dynamic pressure constant. Thus, for any given lift coefficient, the lift, and hence the deflection, was the same even though the Reynolds number of the test was changed. This procedure entailed a small change in Mach number, but probably involved no appreciable compressibility effects at the low Mach numbers involved. Accordingly, tests were made at a dynamic pressure of 50 pounds per square foot in which data were obtained at Reynolds numbers of 4.11, 7.29, and 9.85 million, the respective Mach numbers being 0.182, 0.108, and 0.080. These data are compared in figure 10, and some of the effects of scale are presented in figures 11 to 13. From the comparison in figure 10, it is seen that the same changes in the wing characteristics as previously discussed occur with increasing Reynolds number. Note, however, that over the low-drag range between lift coefficients of 0.1 and –0.1, larger drag coefficients were measured as the test Reynolds number was increased. The evidence available does not indicate that this effect can be attributed either to increasing air-stream turbulence or to changes in the condition of the model surface. In this small range of lift coefficients, increasing the Reynolds number probably caused a forward movement of transition over portions of the wing, resulting in a relatively larger amount of turbulent flow with a consequent increase in drag.

At lift coefficients of 0.2 and above, the data of figure 11 indicate a decrease in drag with increasing Reynolds number, the trend being such that even further drag reduction might be expected at Reynolds numbers above 10 million. The lift and pitching-moment coefficients would apparently be little affected by any further increase of Reynolds number.

The effect of Reynolds number on the variation of the lift-to-drag ratio with lift coefficient is shown in figure 12. Since between lift coefficients of about 0.1 and −0.1 the effect of increasing the Reynolds number is to increase the drag coefficient (figs. 9 and 10), the lift-to-drag ratio decreases with increasing Reynolds number for any constant lift coefficient less than 0.1. Conversely, for any lift coefficient above 0.1 the lift-to-drag ratio increases with increasing Reynolds number.

In figure 13 are summarized the variations of the lift-curve slope at zero lift, minimum drag coefficient, and maximum lift-to-drag ratio with Reynolds number. An increase of the maximum lift-to drag ratio from 17.7 to 20.6 resulted from an increase of the Reynolds number from 4.11 to 9.85 million.

Effectiveness of the Elevon

Effect of Mach number.— The lift, drag, and pitching-moment characteristics of the wing with the elevon deflected in 5° increments from 5° to −20° are shown in figure 14 for a Reynolds number of 2.26 million and Mach numbers between 0.900 and 0.600. Similar data are presented in figure 15 for the wing at a Reynolds number of 4.20 million and a Mach number of 0.190 with the elevon deflected in 5° increments through a range of 5° to −40°.

Figures 16 to 18 are cross plots of the data from figures 14 and 15 showing the variation of the lift and pitching-moment coefficients with elevon deflection for constant angles of attack up to 8°. It may be seen that both lift effectiveness $C_{L_{\delta_e}}$ and pitch effectiveness $C_{m_{\delta_e}}$ decrease as the angle of attack is increased. The data for a

Mach number of 0.190, shown in figure 18, indicate an increase in pitch effectiveness between elevon deflections of -10° and -20°, with pitch effectiveness decreasing for elevon deflections greater than -20° and lift effectiveness decreasing for elevon deflections greater than -30°.

The variation with Mach number of $C_{L_{\delta_e}}$ and $C_{m_{\delta_e}}$, measured over a range of small elevon deflections, is shown in figure 19 for an angle of attack of 0°. At a Mach number of 0.60, the values of $C_{L_{\delta_e}}$ and $C_{m_{\delta_e}}$ are 0.0045 and -0.0053, respectively. The effect of compressibility is small, with an apparent trend toward loss of both lift and pitch effectiveness at Mach numbers greater than 0.850. The slopes obtained at the Mach number of 0.190 have been included for comparison, even though there is some difference in the Reynolds numbers. It is not evident whether the change in pitch effectiveness between Mach numbers of 0.190 and 0.600 is due to the increase in Mach number or to the difference in the test Reynolds numbers..

Effect of Reynolds number.— The lift, drag, and pitching-moment characteristics of the wing with the elevon deflected 0°, -10°, -20°, and -30° are presented in figure 20 for a constant dynamic pressure of 50 pounds per square foot, at Reynolds numbers of 4.20, 7.30, and 9.80 million with corresponding Mach numbers of 0.190, 0.109, and 0.080. There was no appreciable change of the effectiveness parameters $C_{L_{\delta_e}}$ and $C_{m_{\delta_e}}$ with increasing Reynolds numbers between 4.20 and 9.80 million.

Effects of Roughness Strips

Elevon undeflected.— In an effort to extend the linear variation of the pitching-moment coefficient to higher lift coefficients, the wing was tested with roughness intended to induce transition at 0.03c. It was reasoned that by this means separation on the outer portion of the wing might be delayed if the boundary layer could be made turbulent in a region of favorable pressure gradient. In figure 21, the aerodynamic characteristics of the wing with the roughness are compared to the characteristics of the smooth wing for Mach numbers between 0.800 and 0.925 at a constant Reynolds number of 2.29 million. Except for the effect of roughness on minimum drag coefficient, the differences between the results for the two conditions are small, the data for the wing with roughness tending to lie in the direction to indicate an increase in effective Reynolds number. No significant changes with Mach number appear.

The low-drag range at a Mach number of 0.80 has been plotted to an expanded scale in figure 22 in order to compare the magnitude of the minimum drag coefficient of the roughened wing with that of the smooth wing. It may be seen that the minimum drag coefficient of the rough wing has a value of 0.0085; whereas that of the smooth wing has a value of 0.0049.

Comparisons of the wing characteristics with and without roughness are made in figure 23 for tests at Reynolds numbers of 4.10 and 7.30 million with corresponding Mach numbers of 0.190 and 0.109. The changes in the aerodynamic characteristics caused by the roughness strips were more pronounced at the low Mach numbers (fig. 23) than at the higher Mach numbers (fig. 21); the roughness strips increased the drag coefficients somewhat but caused only small changes of the lift and pitching-moment coefficients. The ineffectiveness of the roughness strips may have been due to their being improperly positioned on the wing surfaces, but time did not permit a thorough investigation to ascertain if other chordwise locations of the roughness strips would be more effective.

<u>Elevon deflected -10°</u>.- For a Mach number of 0.900, in figure 24(a) the characteristics of the wing with roughness strips at 0.03c for Reynolds numbers of 2.30 and 3.60 million are compared to the characteristics of the smooth wing at a Reynolds number of 2.30 million. A small increase in the drag coefficients and a small, nearly constant reduction of the pitching-moment coefficients measured near zero lift were the only effects caused by the roughness strips for the Reynolds number of 2.30 million. Increase of the Reynolds number from 2.30 to 3.60 million for the wing with roughness had no appreciable effect.

In figure 24(b), a comparison is afforded between the characteristics of the wing with roughness strips and with a smooth surface for a Mach number of 0.190 and a Reynolds number of 4 million. The roughness strips had a negligible effect on the pitching-moment coefficients.

Effect of Model Deflection Under Varying Loads

No attempt was made to measure the magnitude of the wing deflection under varying loads because of the difficulties in making observations through the small windows of the pressure tunnel. Data are presented in figure 25, however, showing the effect of doubling the load on the wing at any given lift coefficient (i.e., the effect of doubling the dynamic pressure), while the Reynolds number was held constant at 9.75 million and the Mach number allowed to increase from 0.080 to 0.160. The data show only small effects due to distortion.

CONCLUSIONS

An investigation was made of a semispan model of a wing swept back 63° and having an aspect ratio of 3.5. These tests were conducted to determine the separate effects of Mach and Reynolds number on the aerodynamic characteristics of the wing and on the effectiveness of an elevon.

1. The aerodynamic center of the wing shifted rearward near a lift coefficient of 0.2; whereas above a lift coefficient of approximately 0.4 there was an abrupt forward shift of the aerodynamic center.

2. As the Mach number was increased from 0.160 to 0.925 at Reynolds numbers of 2.35 and 3.55 million in the low lift-coefficient range (lift coefficient less than 0.2), the following effects of compressibility occurred:

   (a) The lift-curve slope at zero lift increased gradually from 0.043 to 0.048 per degree ($R = 3.55$ million).

   (b) There was an increase in the static longitudinal stability, the aerodynamic center at zero lift moving aft from 42.4 to 44.6 percent of the mean aerodynamic chord.

   (c) The maximum lift-to-drag ratio decreased from 18 to 14.7 ($R = 3.55$ million).

   (d) At a Mach number of 0.60, the pitch effectiveness (rate of change of pitching-moment coefficient per degree of elevon deflection) had a value of −0.0053, and the lift effectiveness (rate of change of lift coefficient per degree of elevon deflection) had a value of 0.0045. These values were not appreciably changed by varying the Mach number from 0.60 to 0.90 ($R = 2.26$ million).

3. The effects of increasing Reynolds number at an approximately constant Mach number and at a constant dynamic pressure of 50 pounds per square foot in the low lift-coefficient range (lift coefficient less than 0.2) as determined from these tests may be summarized as follows:

(a) The lift-curve slope at zero lift decreased from 0.045 to 0.042 per degree.

(b) There was little change in the static longitudinal stability, the aerodynamic center remaining at approximately 42.4 percent of the mean aerodynamic chord.

(c) The maximum lift-to-drag ratio increased from 17.7 to 20.6.

(d) The elevon pitch effectiveness and lift effectiveness were little changed by the variation of Reynolds number.

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TABLE I.— SUMMARY OF TESTS

Condition	Mach number	Reynolds number, $R \times 10^{-6}$	Dynamic pressure (lb/sq ft)
Elevon undeflected, smooth surface	0.180 to 0.925	2.35	Varying
Do.	0.160 to 0.925	3.55	Varying
Do.	0.180	2.35 to 10.30	Varying
Do.	0.182 to 0.080	4.11 to 9.85	50
Do.	0.080 to 0.160	9.75	53 and 105
Elevon deflected, smooth surface	0.600 to 0.900	2.26	Varying
Do.	0.190	4.00	50
Do.	0.190 to 0.080	4.20 to 9.80	50
Elevon undeflected, roughness strips at 0.03c	0.800 to 0.925	2.29	Varying
Do.	0.190 and 0.109	4.10 and 7.30	50
Elevon deflected, roughness strips at 0.03c	0.900	2.30 and 3.60	120 and 208
Do.	0.190	4.00	50

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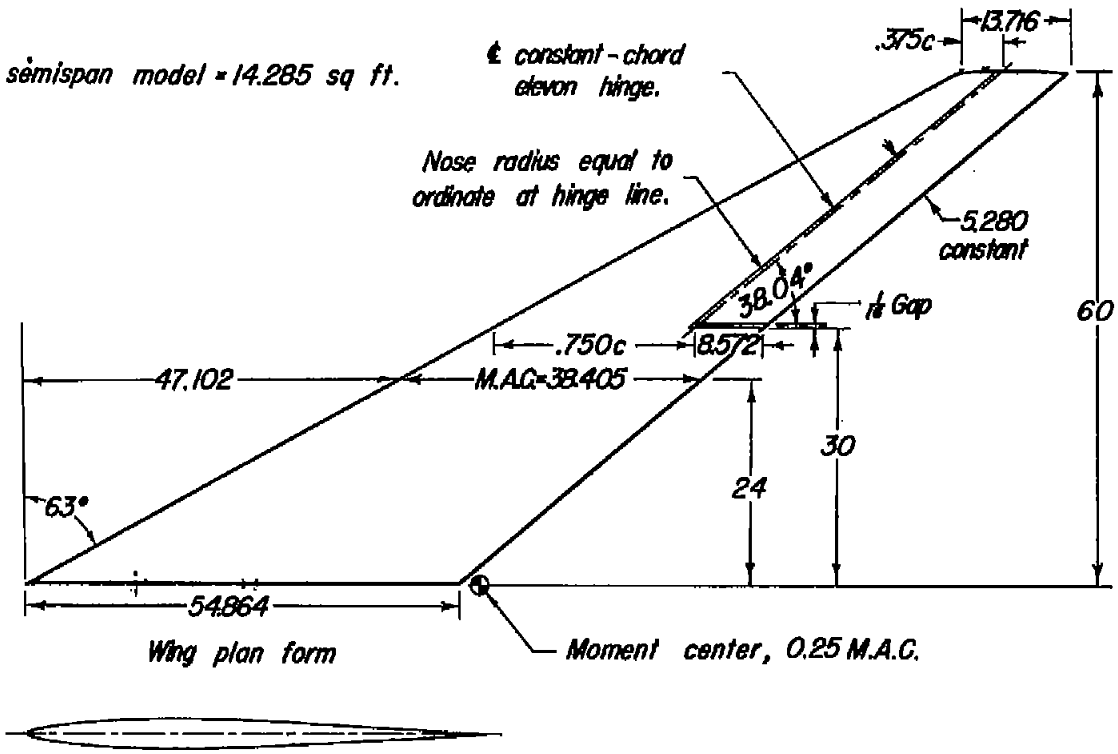
Area of the semispan model = 14.285 sq ft.



Wing plan form

Typical section parallel to the air stream, NACA 64A006.

Dimensions shown in inches unless otherwise noted.

LER = 0.246%C

Figure 1.- Geometry of the semispan model of a wing swept back 63°. Aspect ratio, 3.5; taper ratio, 0.25.

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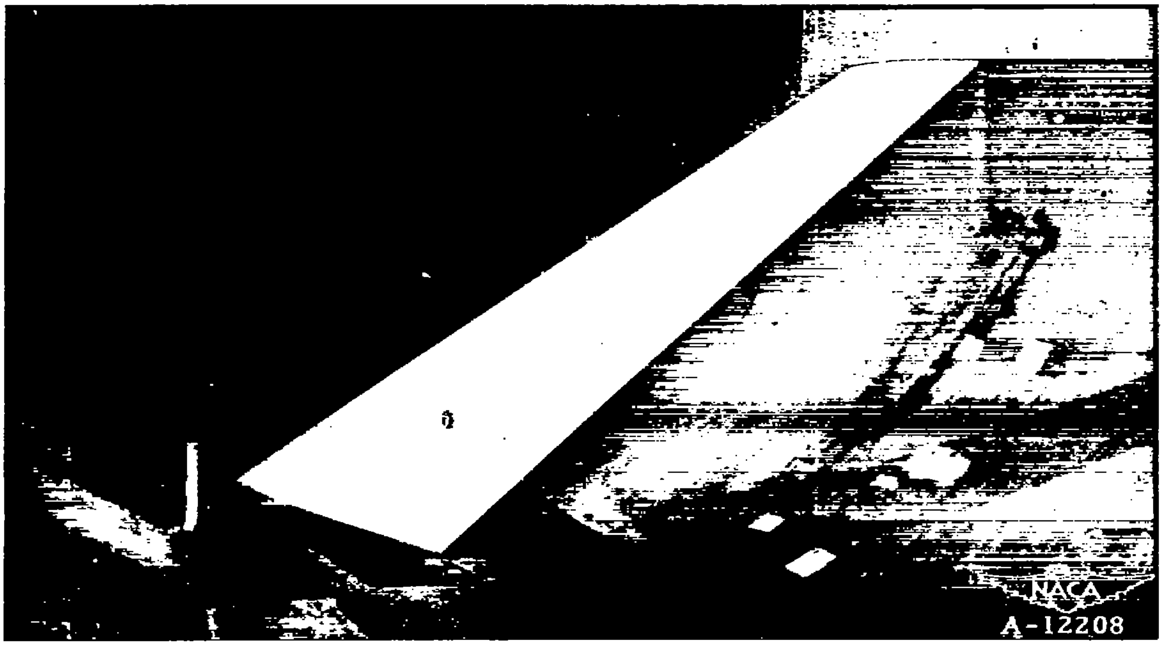
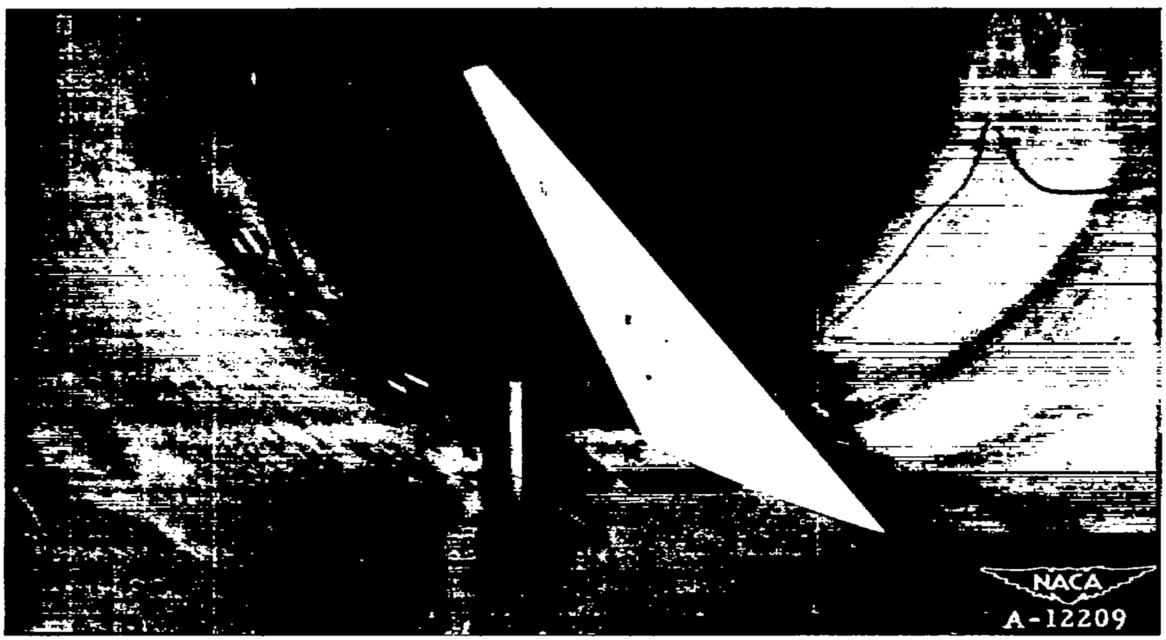


(a) Rear view.



(b) Front view.

Figure 2.– Semispan model of a wing swept back 63° mounted in the 12-foot pressure wind tunnel.

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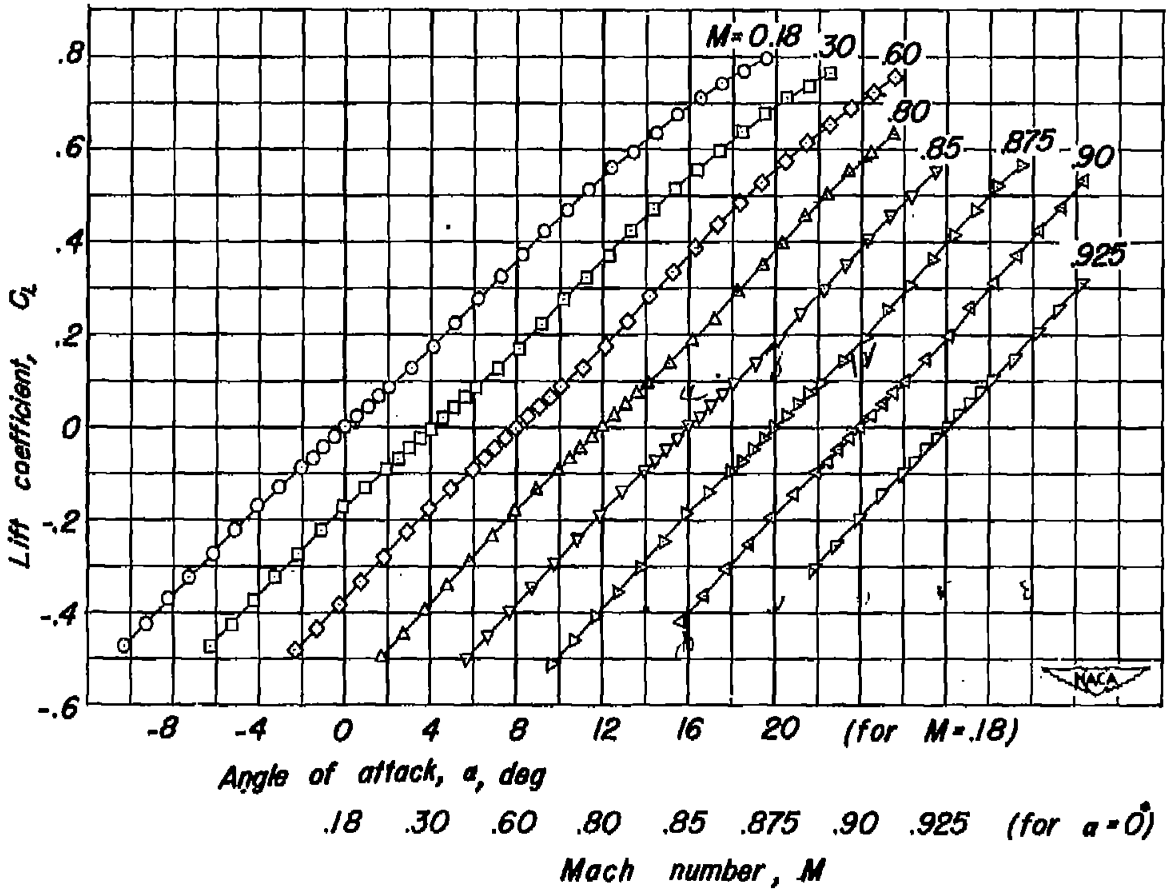

(a) C_L vs α

Figure 3.- The effect of Mach number on the aerodynamic characteristics of a wing swept back 63° at a Reynolds number of 2,350,000.

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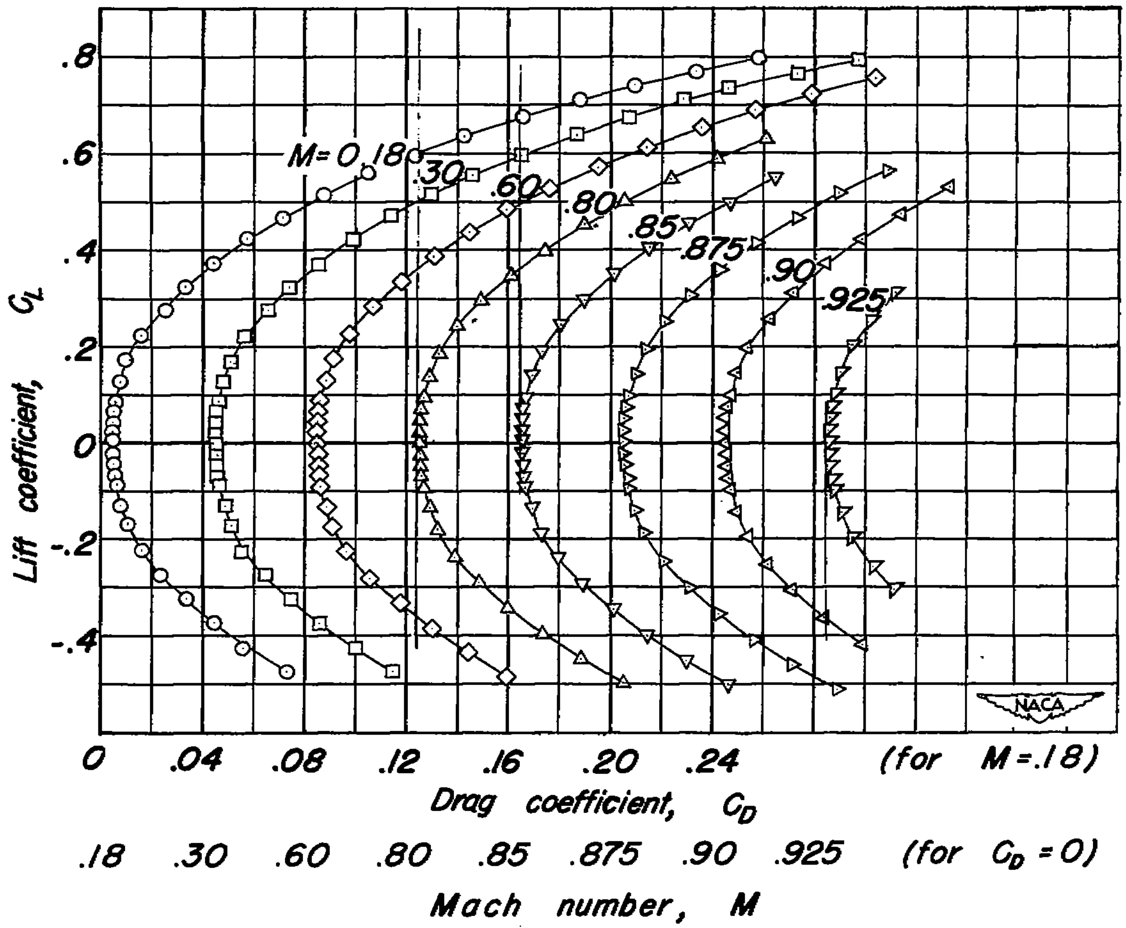

(b) C_L vs C_D

Figure 3.- Continued.

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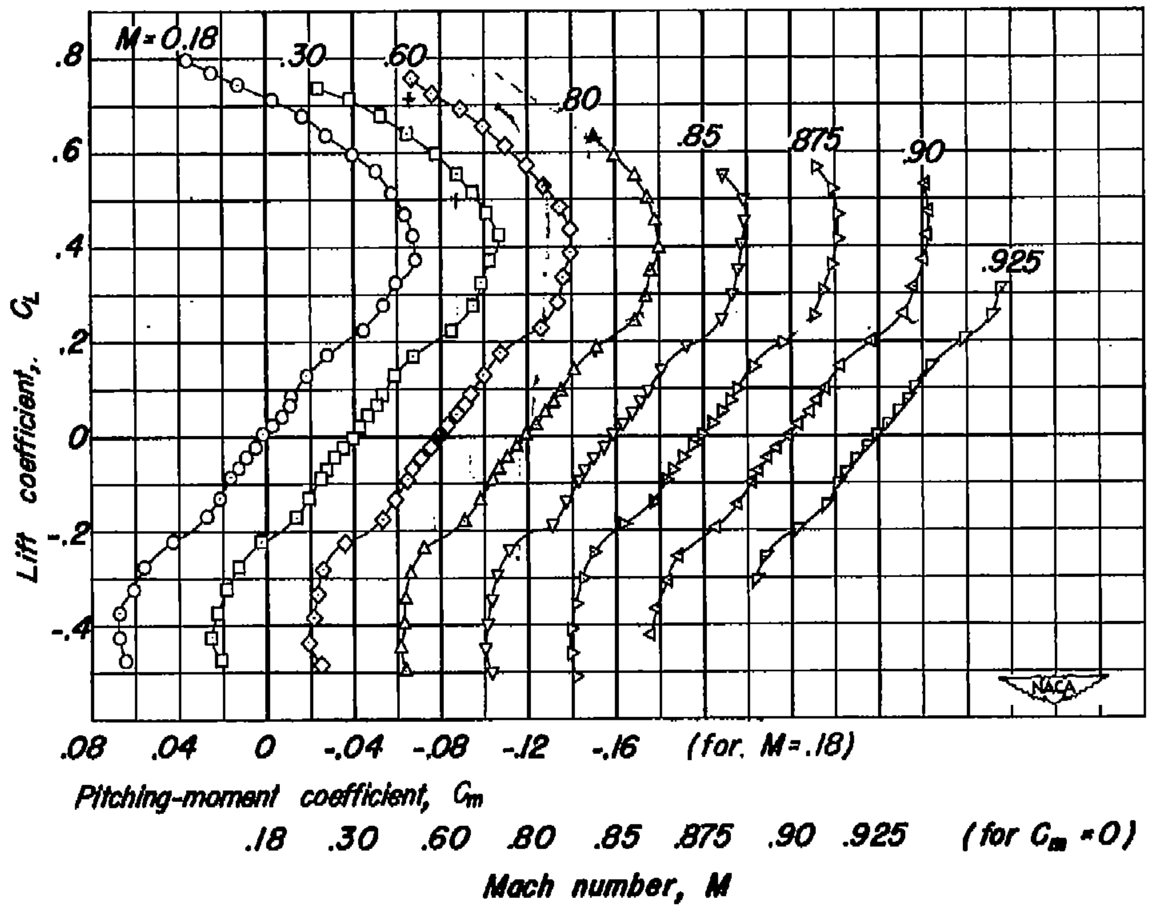

(c) C_L vs C_m

Figure 3.— Concluded.

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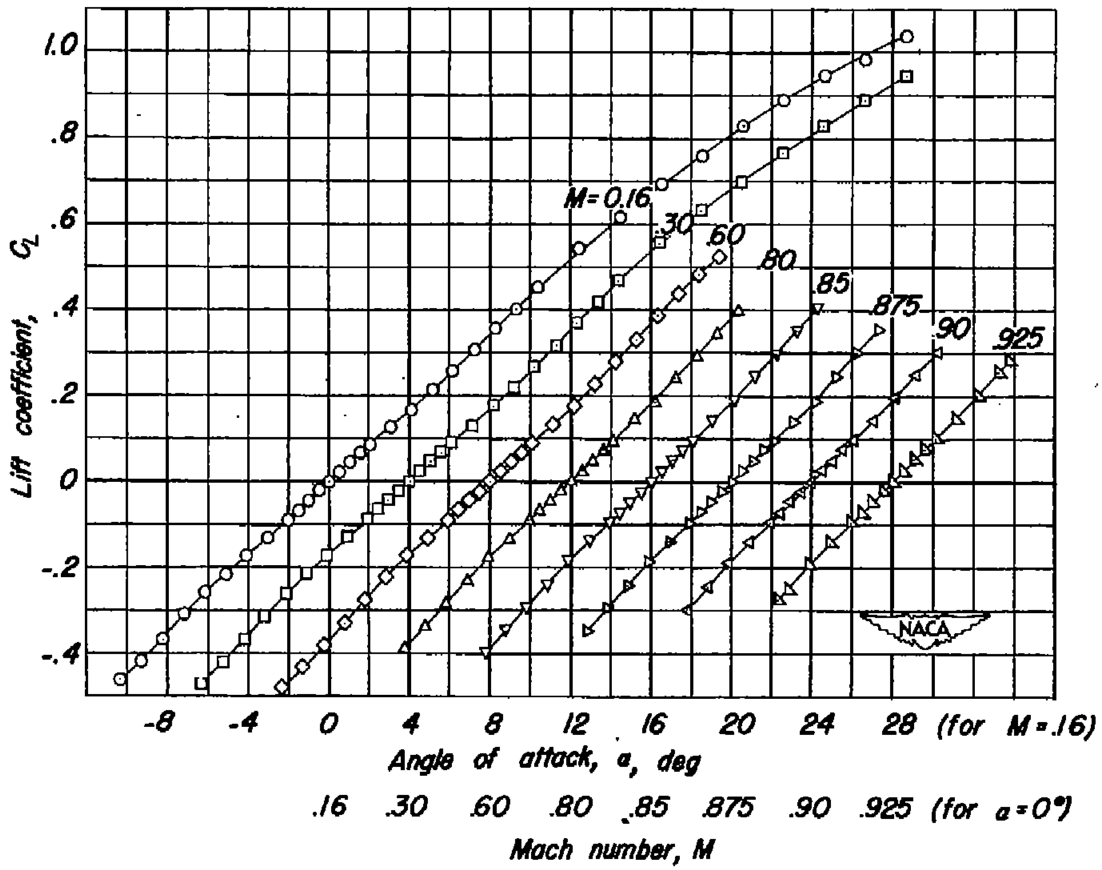

(a) C_L vs α

Figure 4.- The effect of Mach number on the aerodynamic characteristics of a wing swept back 63° at a Reynolds number of 3,550,000.

[redacted]

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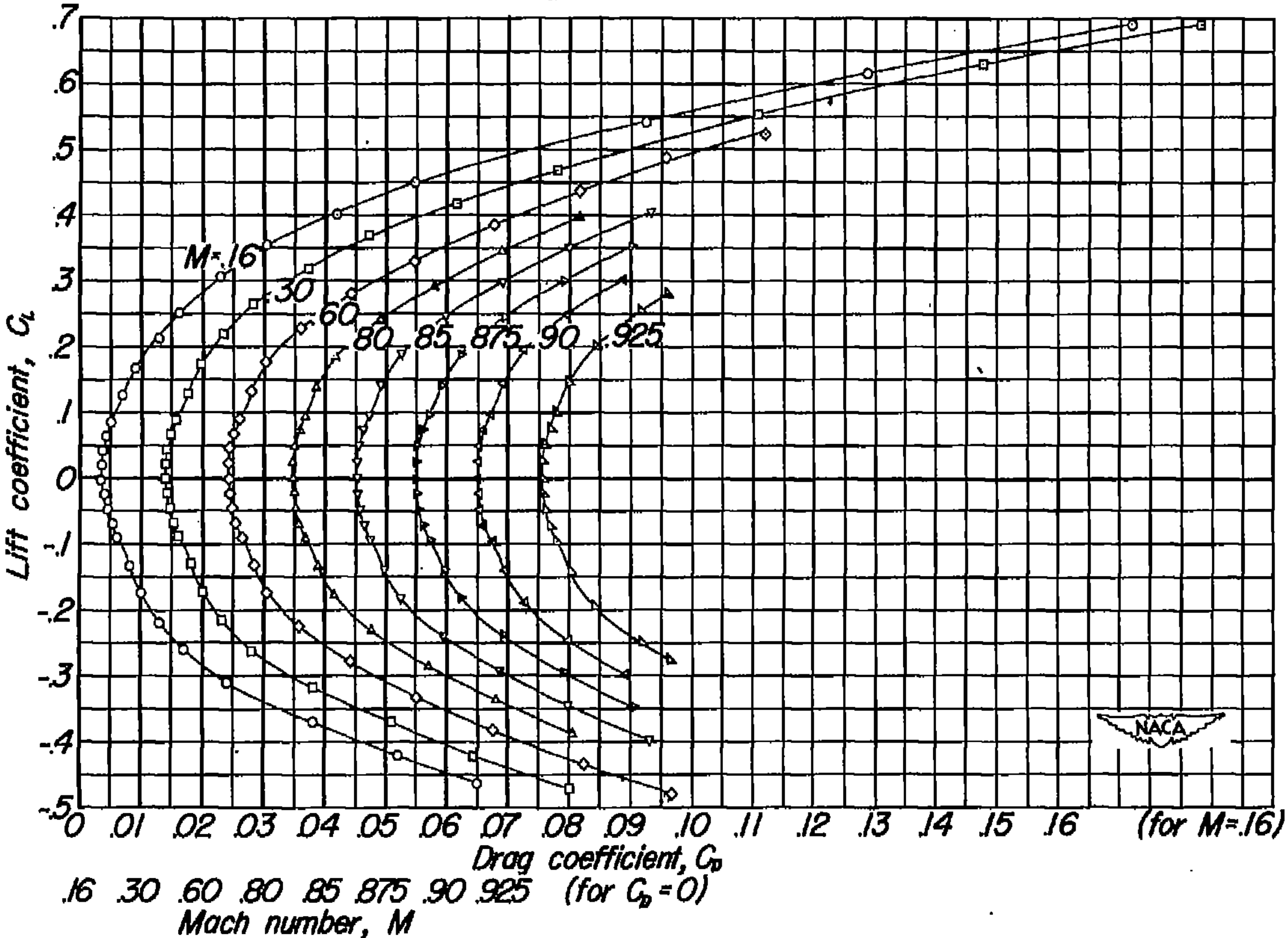
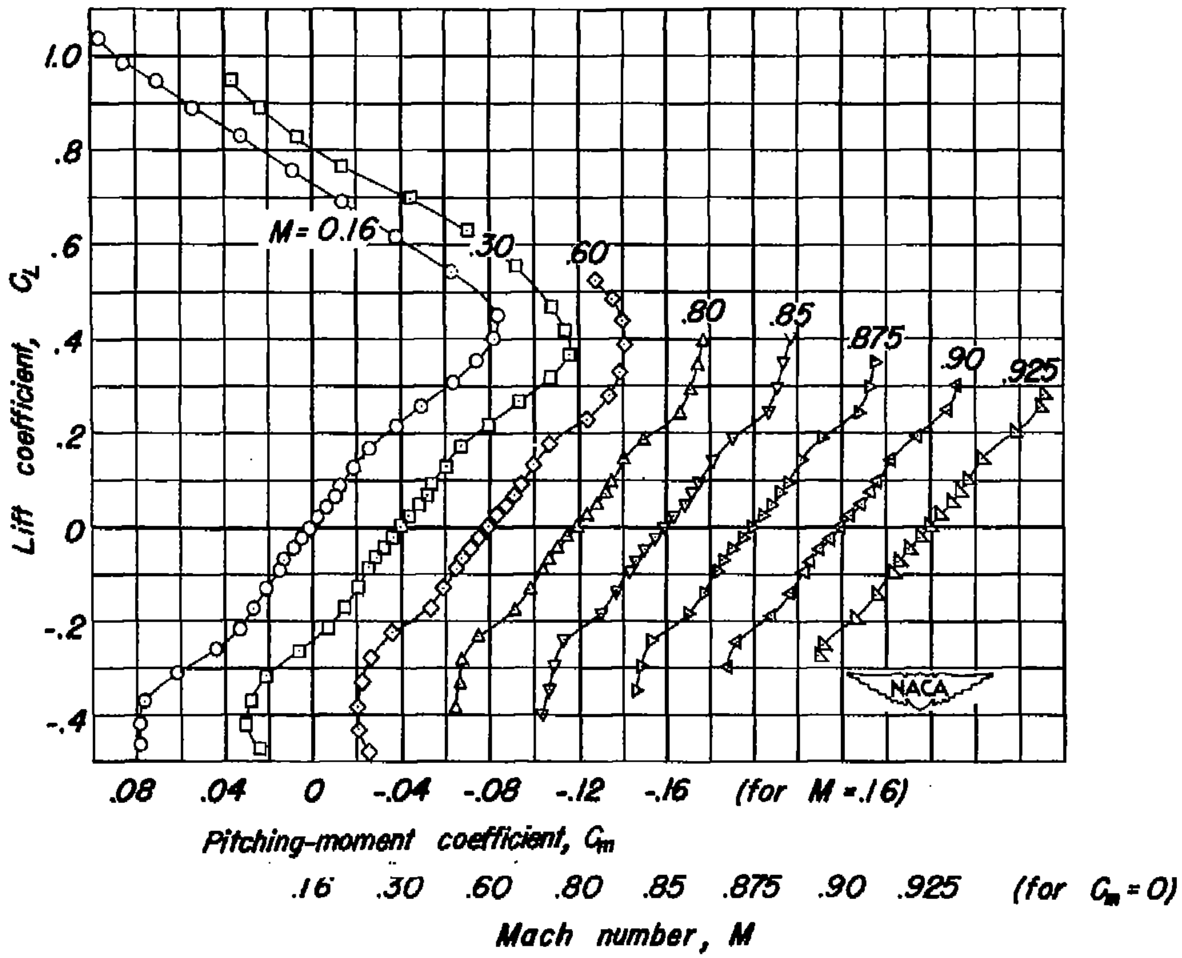


(b) C_L vs C_D

Figure 4.- Continued.

[redacted]

[redacted]



(c) C_L vs C_m

Figure 4.- Concluded.

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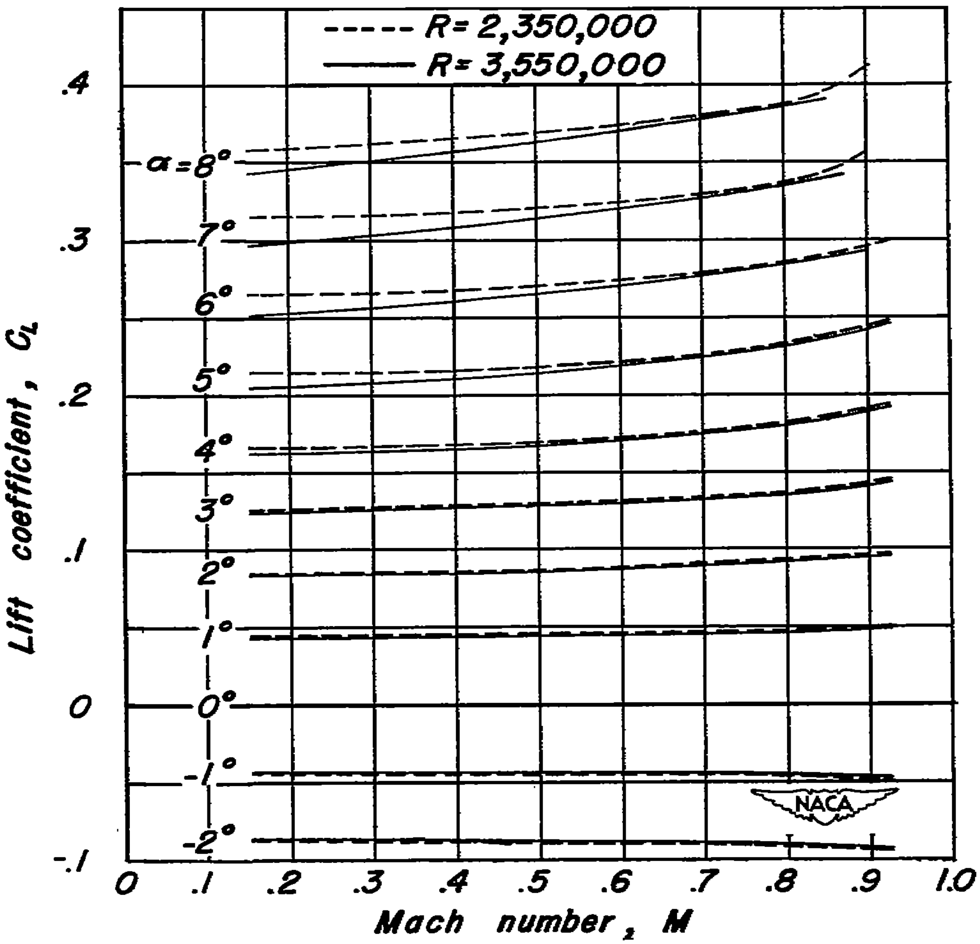
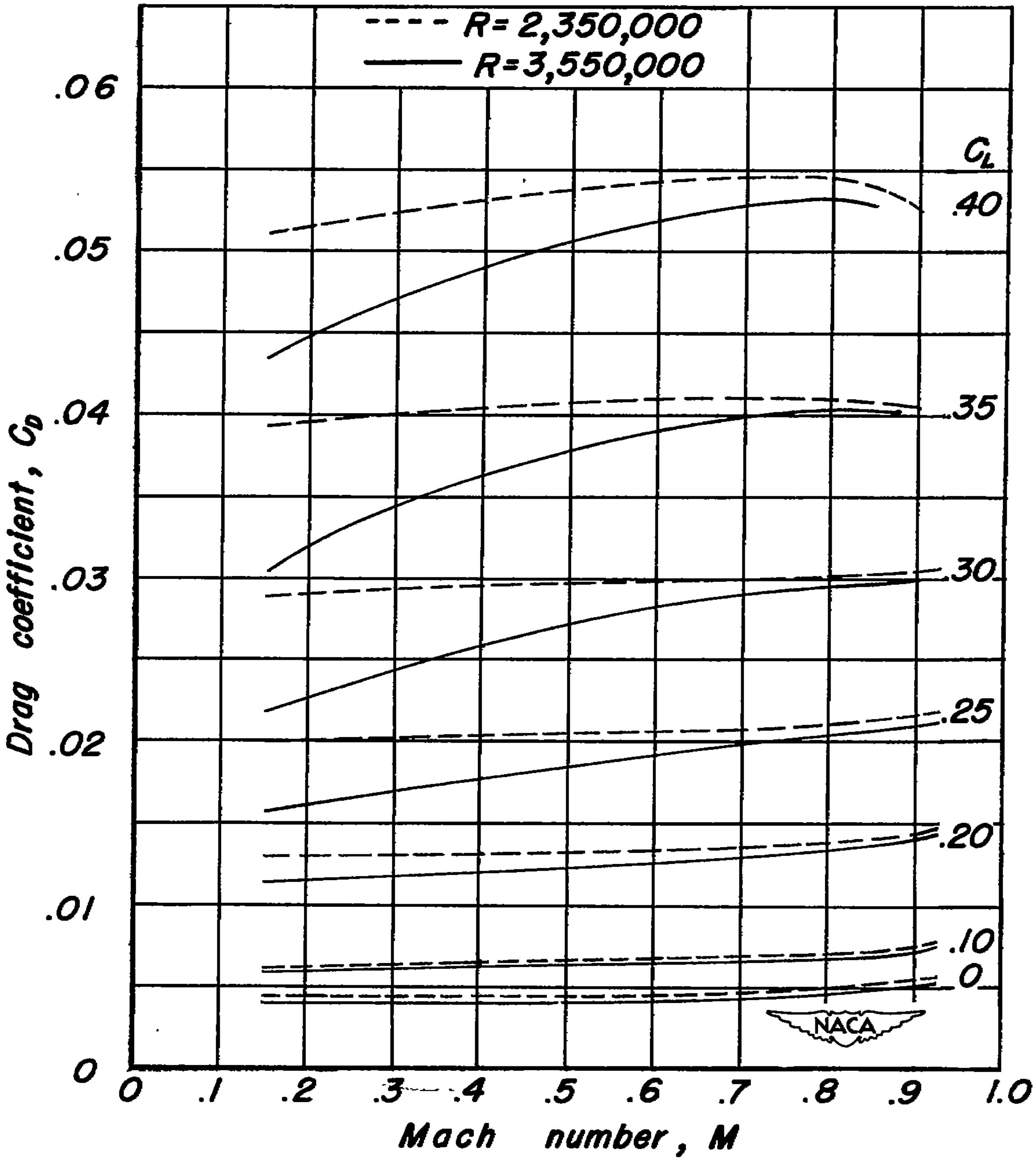


(a) C_L vs M

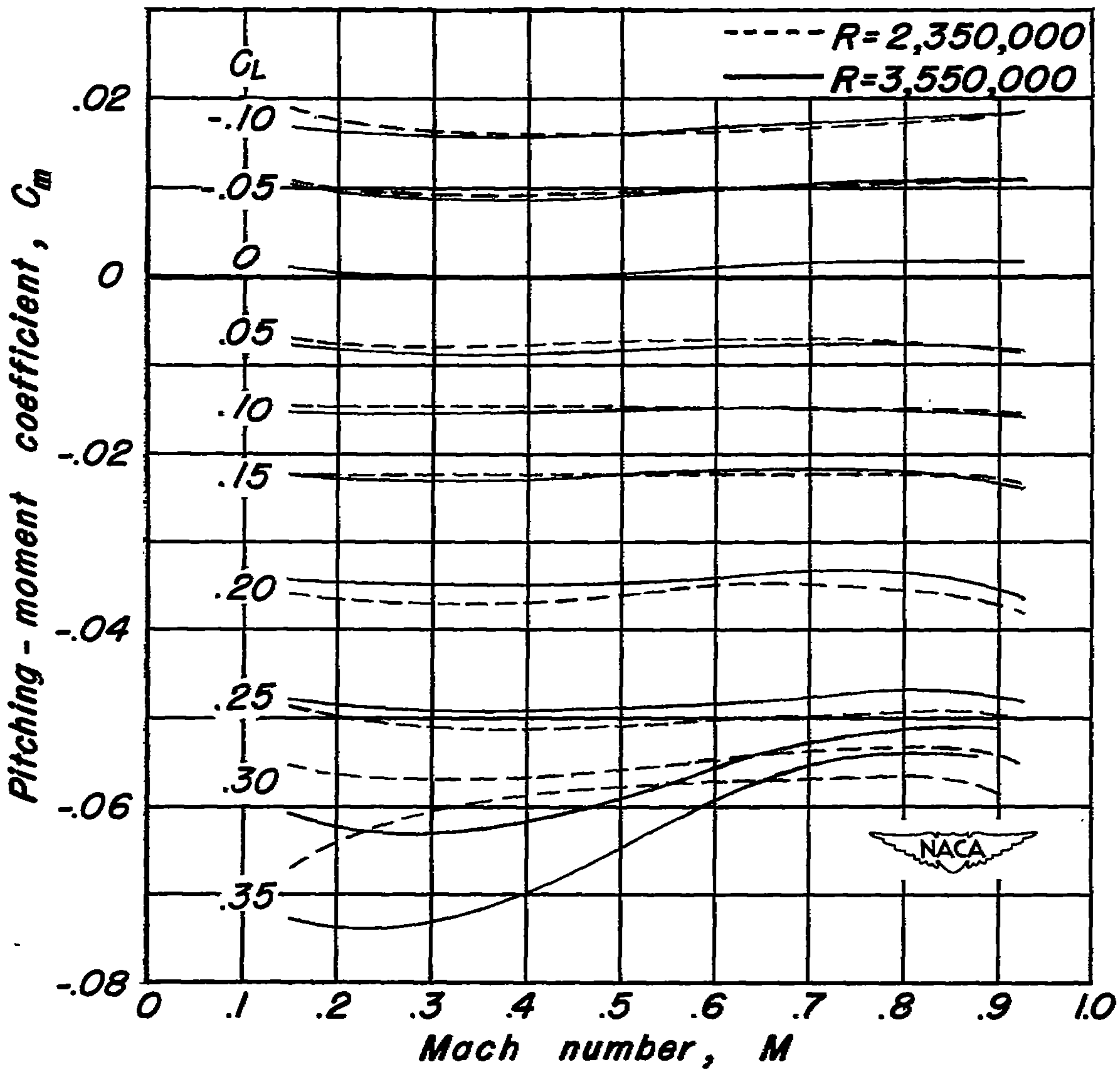
Figure 5.- The variation with Mach number of lift, drag, and pitching-moment coefficients for a wing swept back 63° at Reynolds numbers of 2,350,000 and 3,550,000.



(b) C_D vs M

Figure 5.- Continued

[redacted]



(c) C_m vs M

Figure 5.- Concluded.

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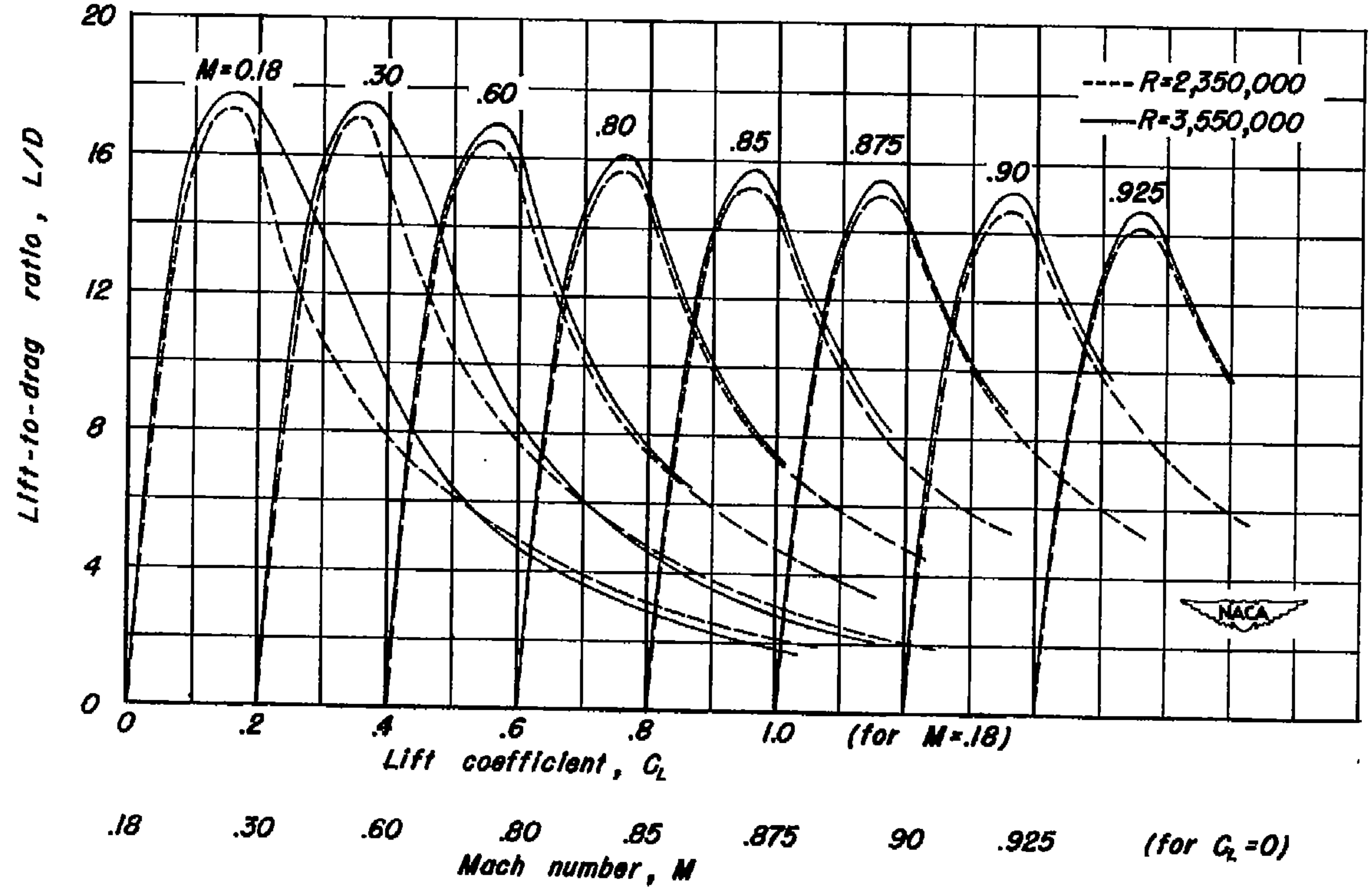

Figure 6.-The variation of lift-to-drag ratio with lift coefficient at several Mach numbers for a wing swept back 63° at Reynolds numbers of 2,350,000 and 3,550,000.

[redacted]

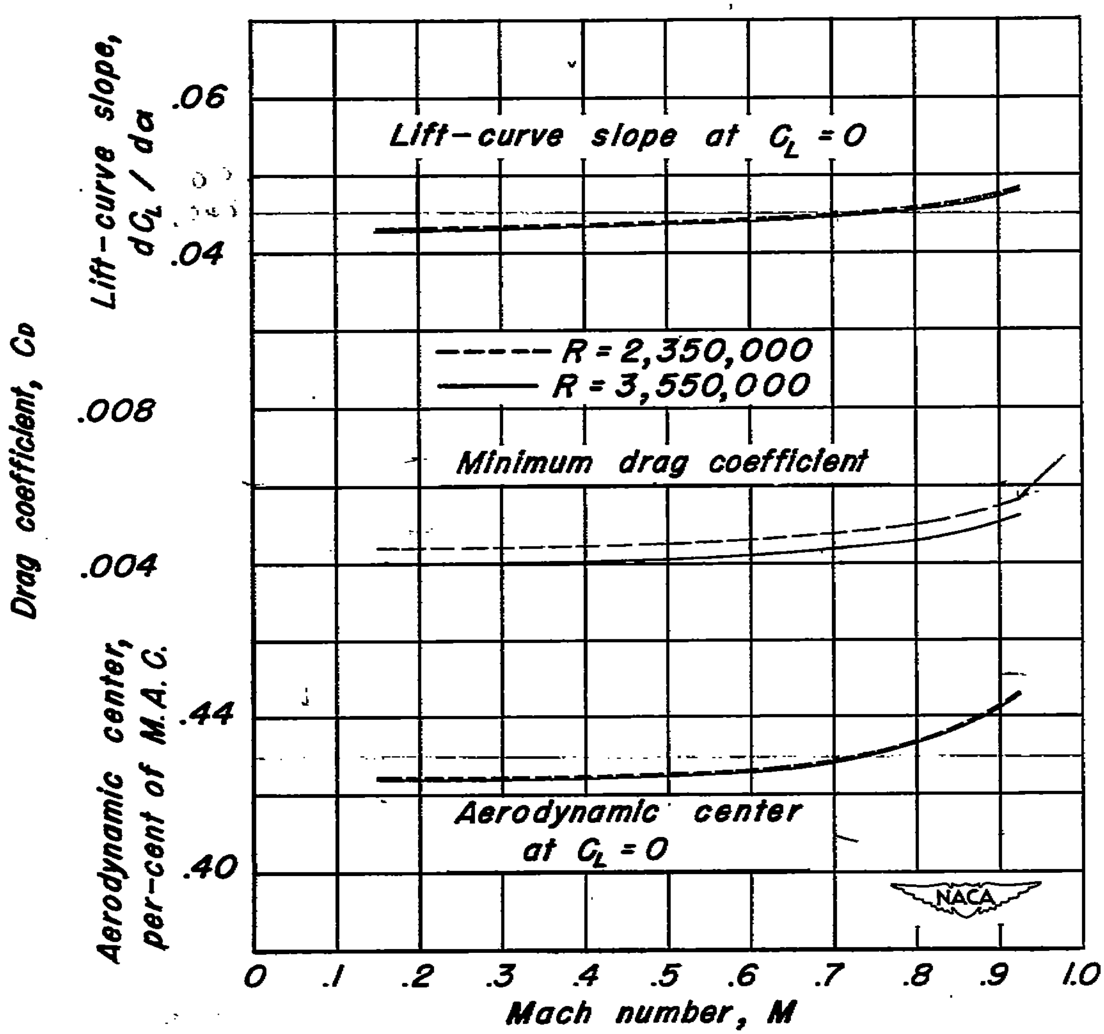

Figure 7.— The variation with Mach number of the lift-curve slope, minimum drag coefficient, and aerodynamic center for a wing swept back 63° at Reynolds numbers of 2,350,000 and 3,550,000.

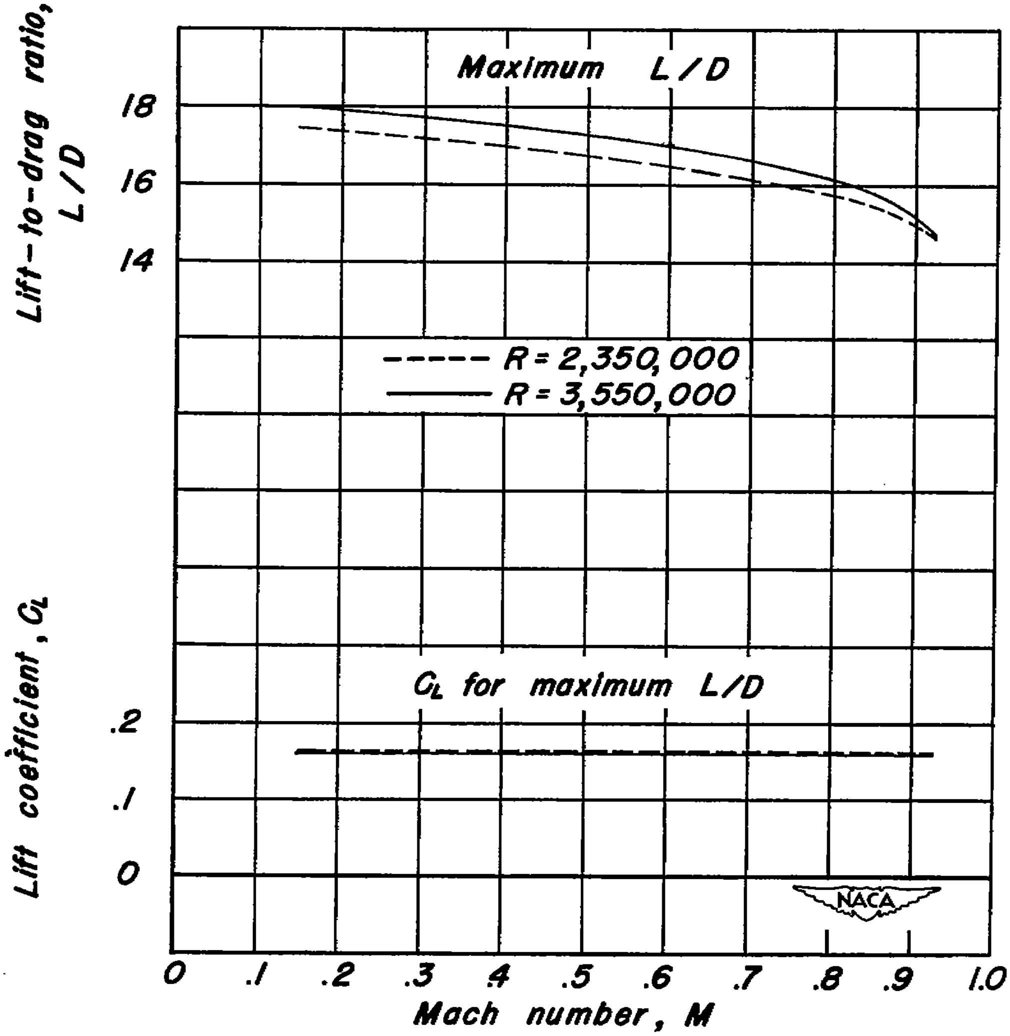

Figure 8.— The variation with Mach number of the maximum lift-to-drag ratio and lift coefficient for maximum lift-to-drag ratio for a wing swept back 63° at Reynolds numbers of 2,350,000 and 3,550,000.

[redacted]

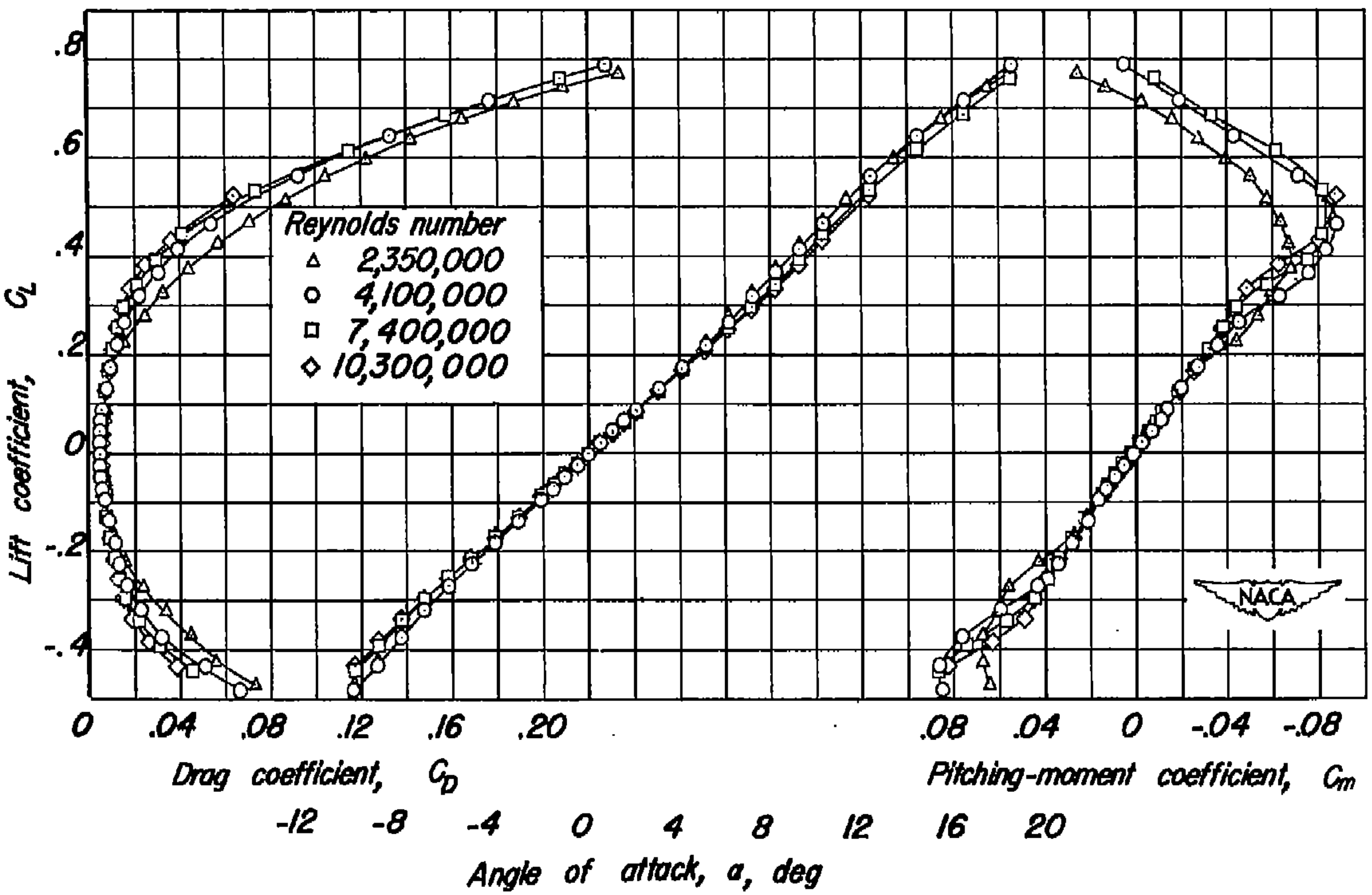

Figure 9.— The effect of Reynolds number on the aerodynamic characteristics of a wing swept back 63° at a Mach number of 0.18.

[redacted]

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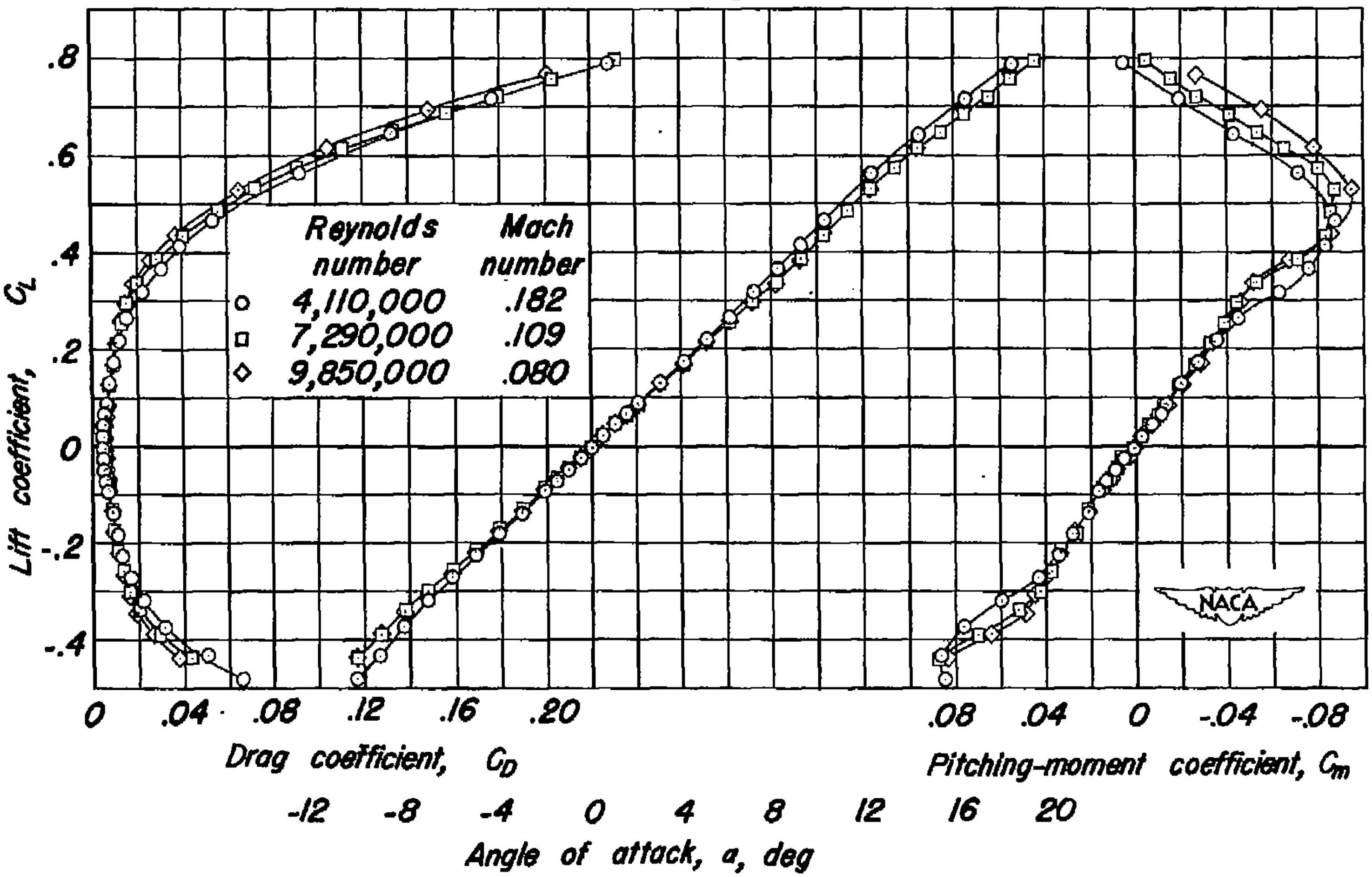

Figure 10.- The effect of Reynolds number on the aerodynamic characteristics of a wing swept back 63° at a constant dynamic pressure, q = 50 lb/sq ft.

[redacted]

[redacted]

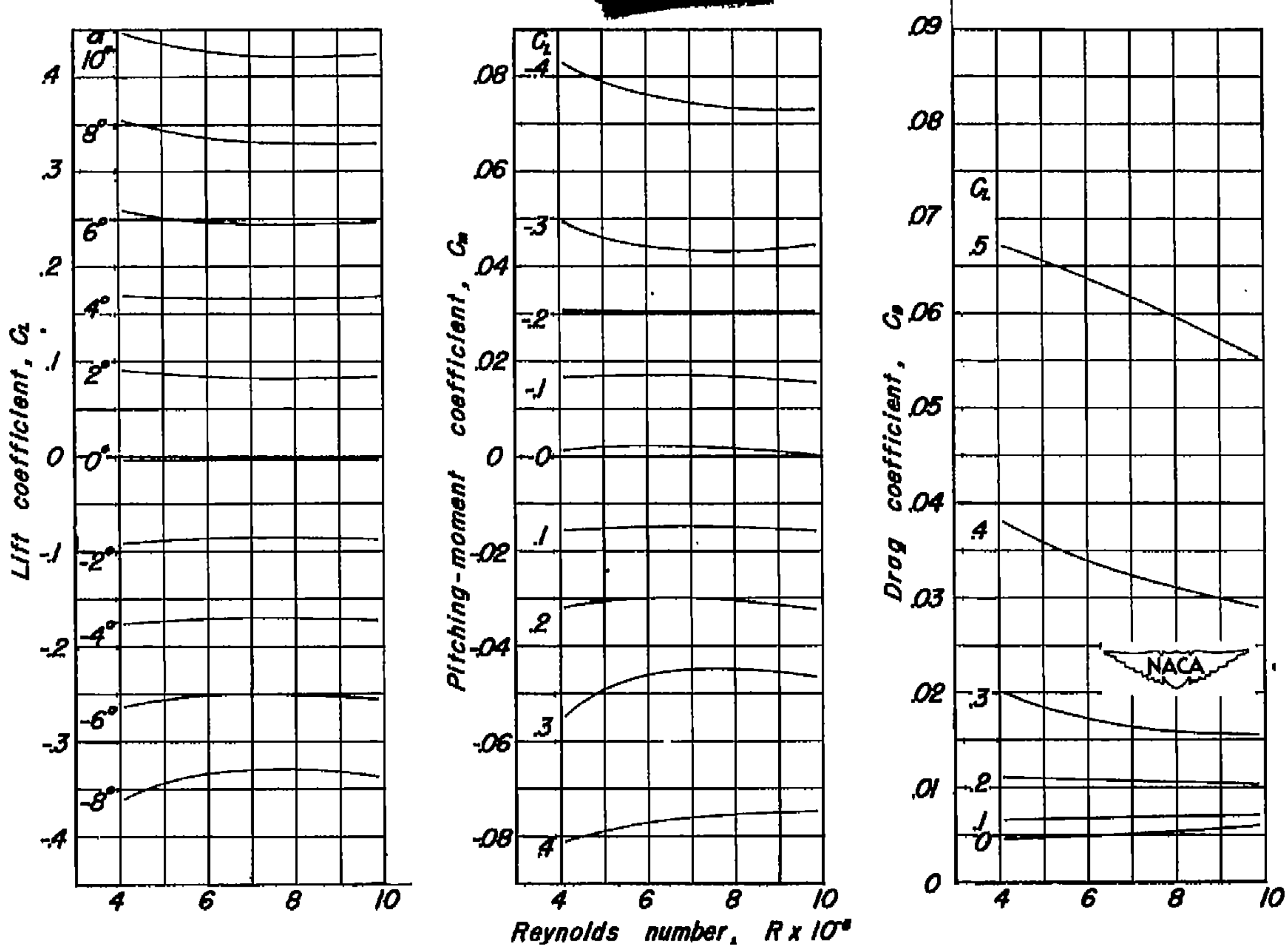

Figure 11.- The variation with Reynolds number of the lift, drag, and pitching-moment coefficients for a wing swept back 63° at a constant dynamic pressure, q = 50 lb/sq ft.

[redacted]

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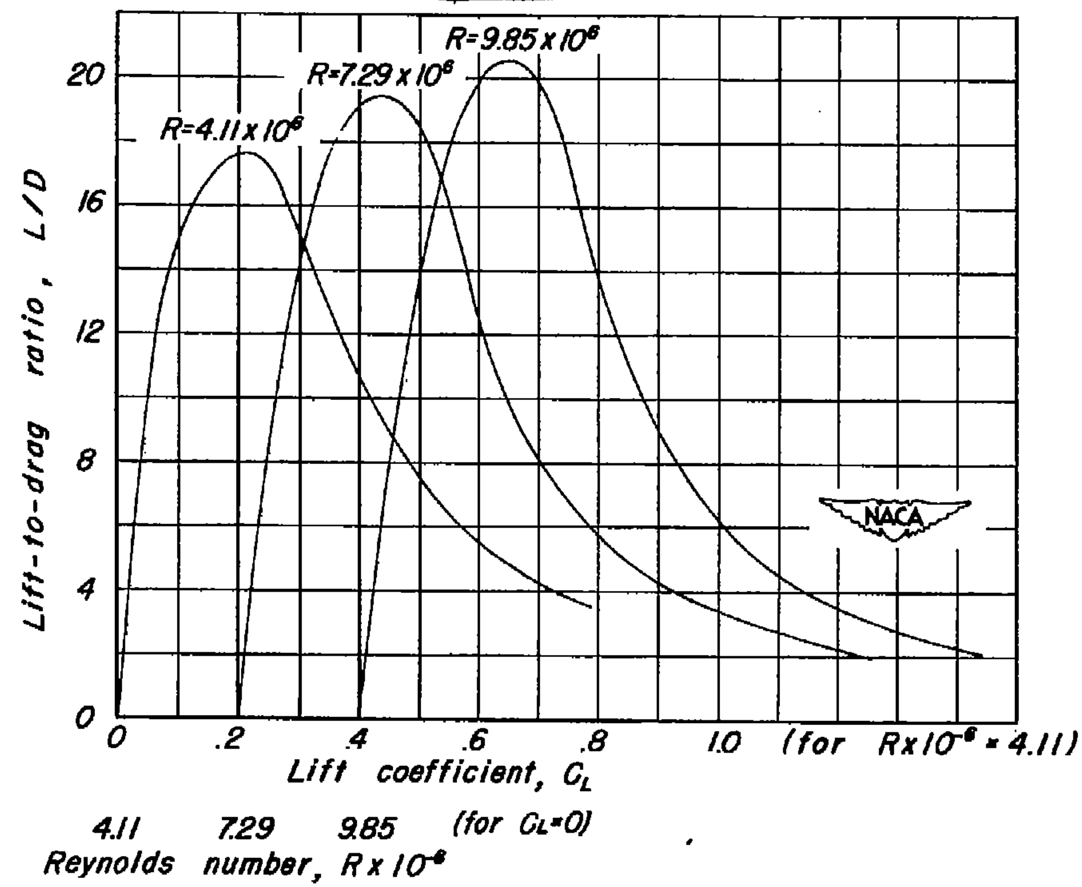


Figure 12.- The variation of lift-to-drag ratio with lift coefficient at three Reynolds numbers for a wing swept back 63° at a constant dynamic pressure, $q = 50$ lb/sq ft.

[redacted]

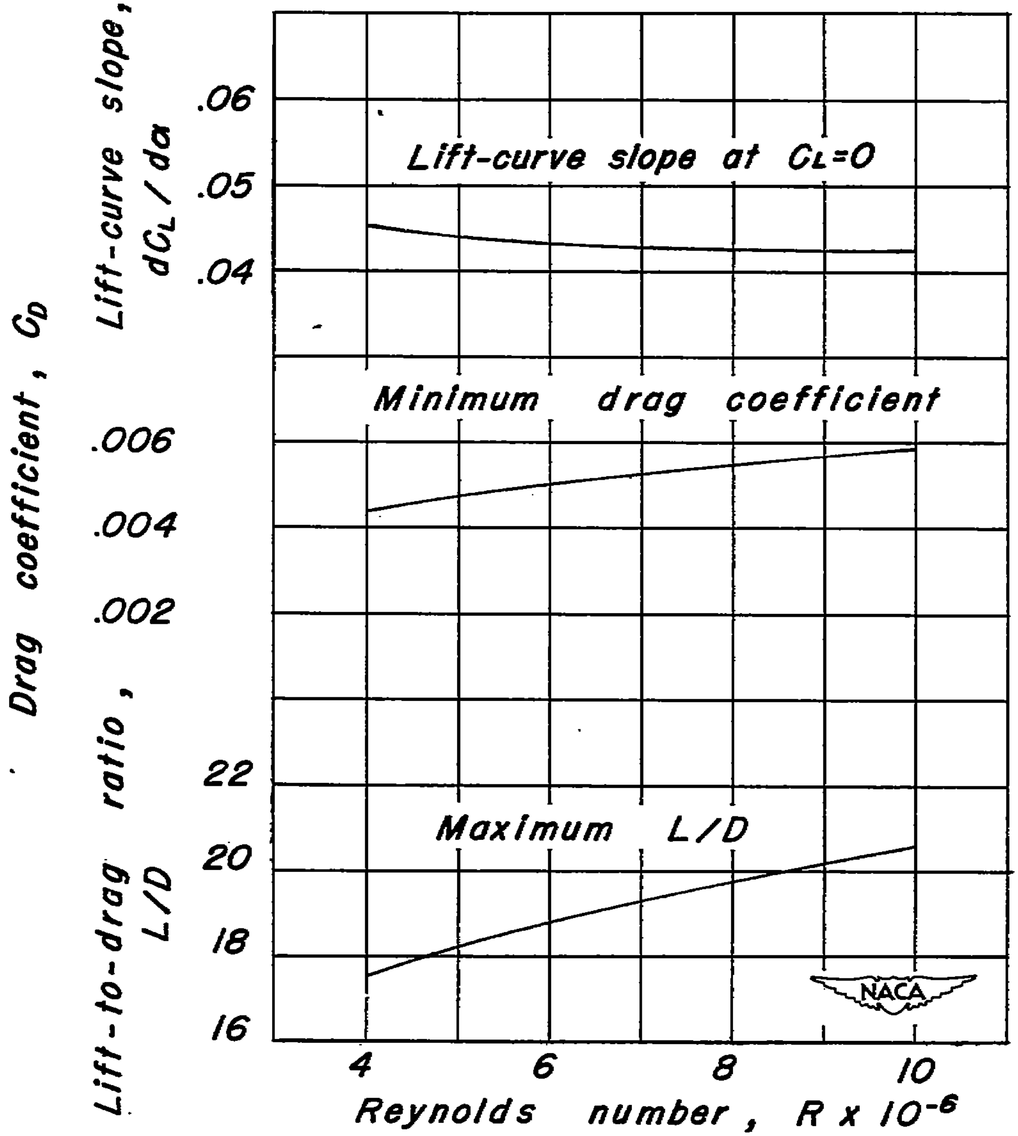
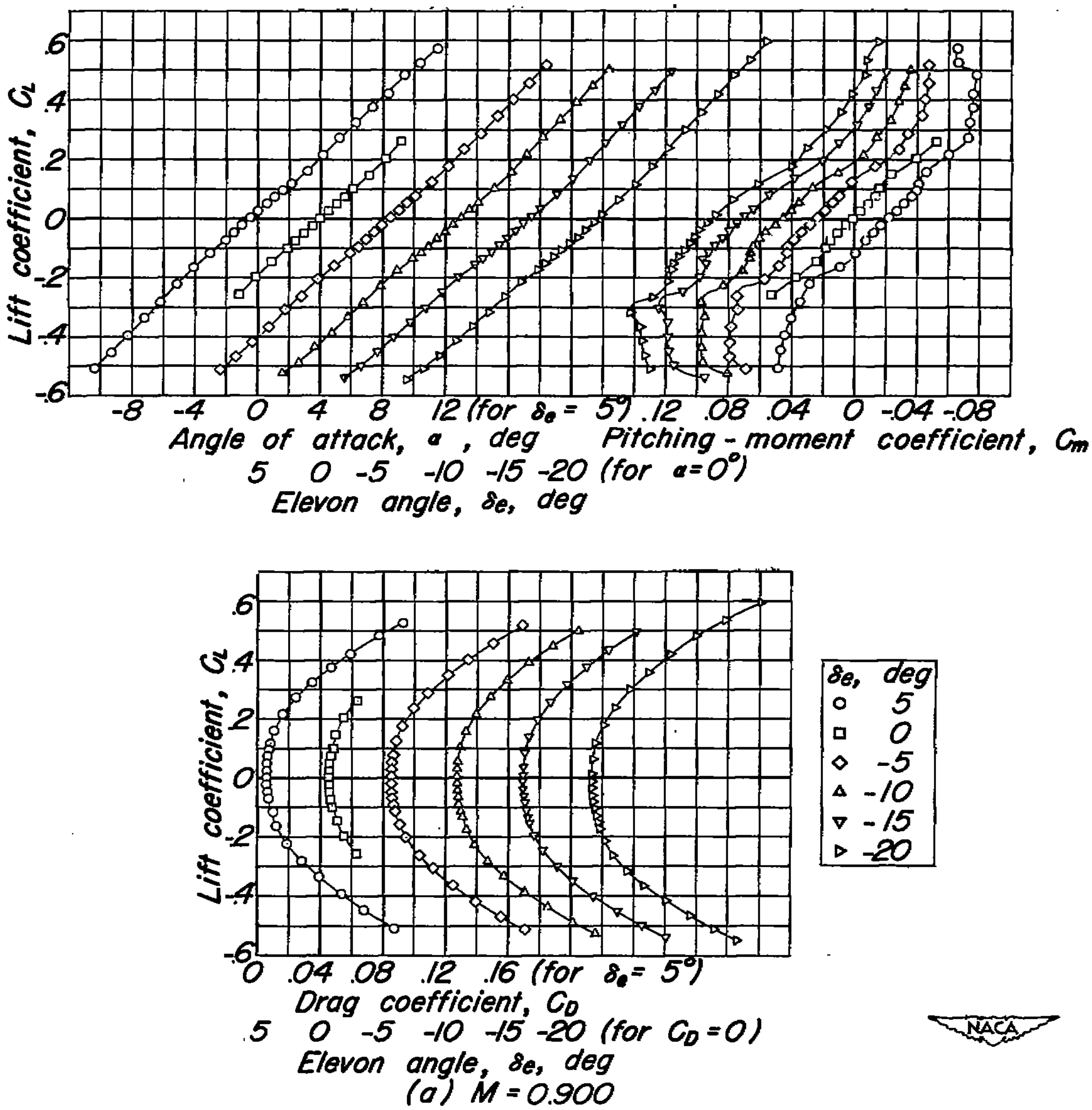
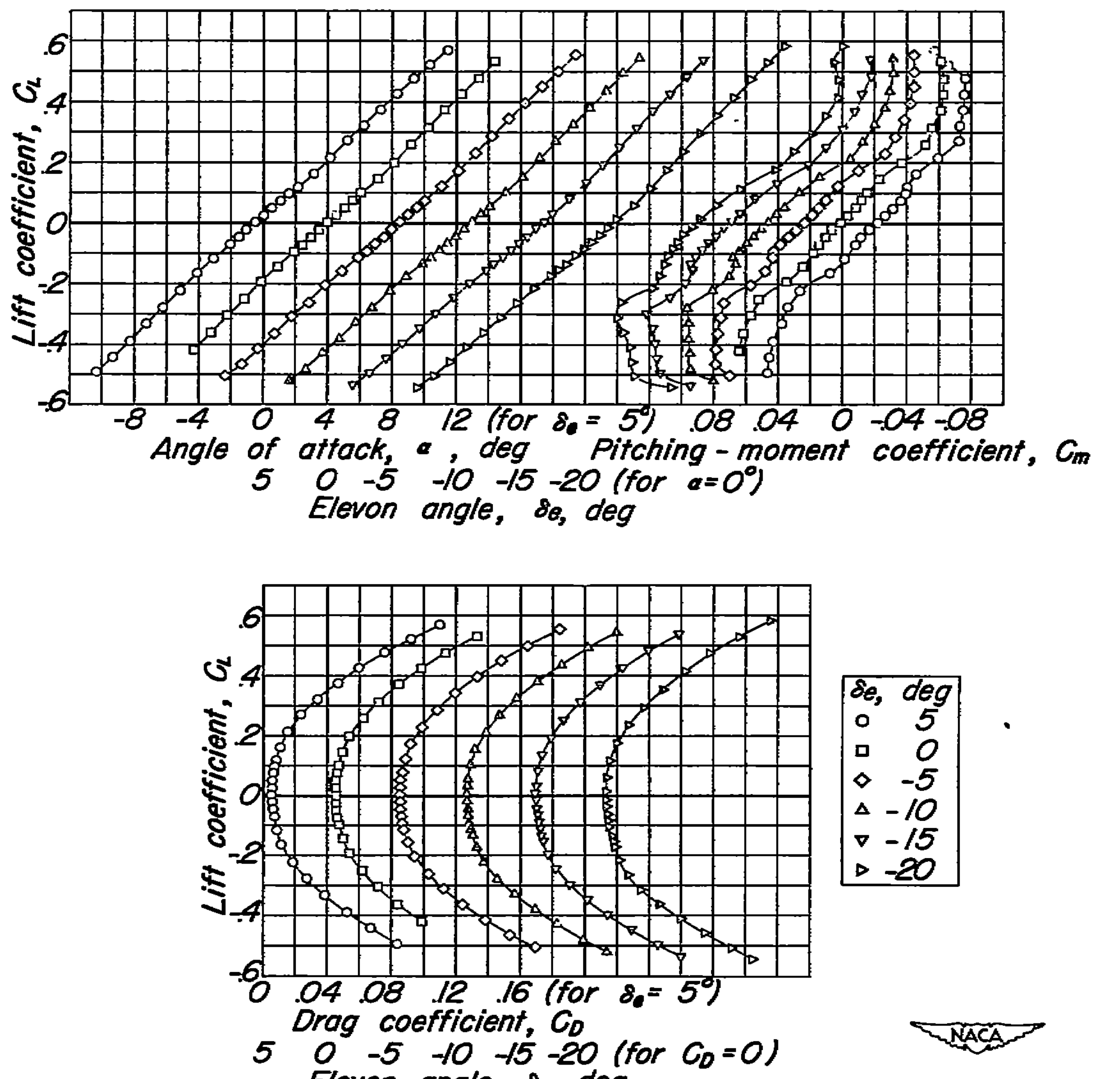


Figure 13.- The variation with Reynolds number of the lift-curve slope, minimum drag coefficient, and maximum lift-to-drag ratio for a wing swept back 63° at a constant dynamic pressure, q=50 lb/sq ft.



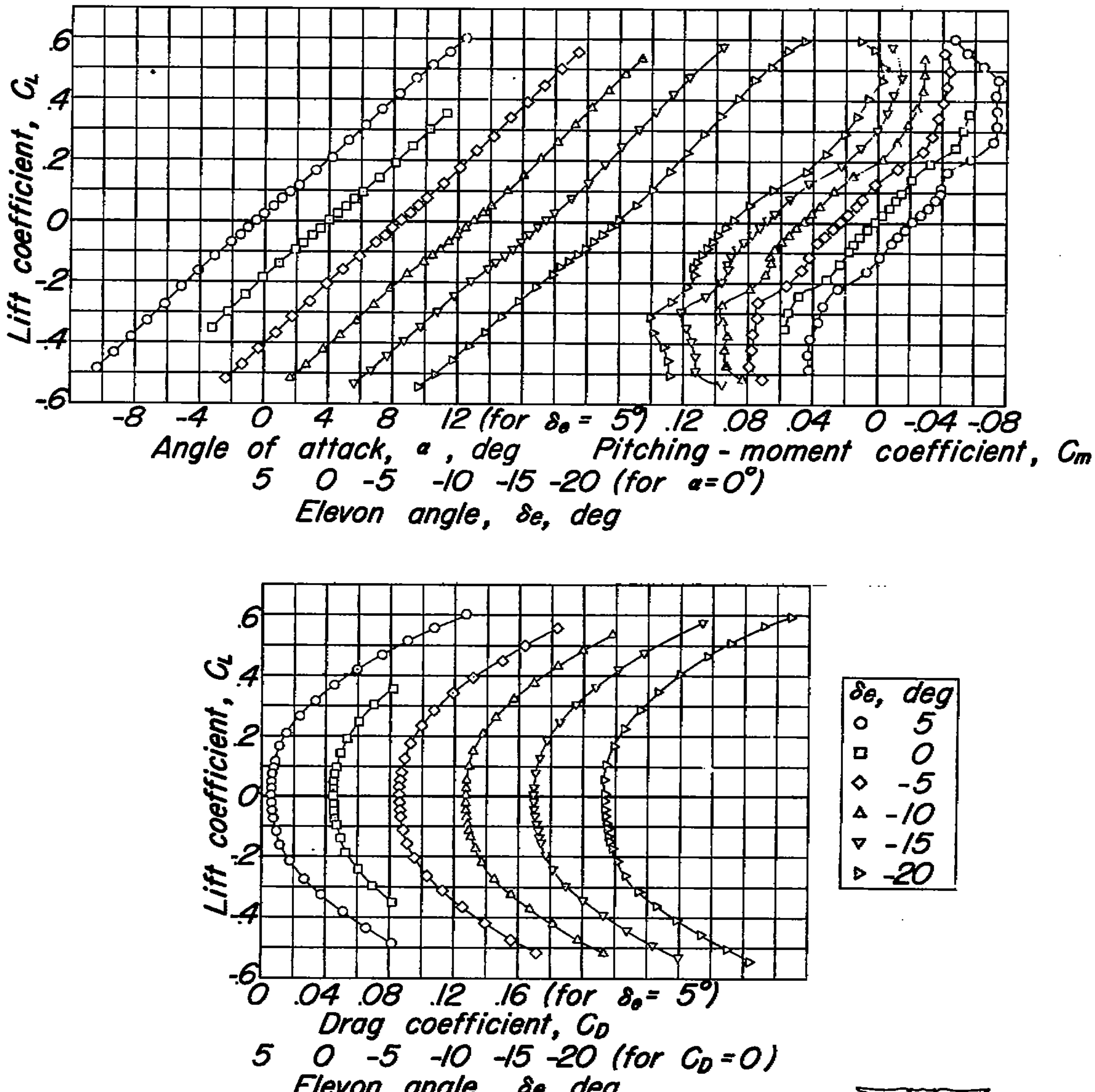
(a) $M = 0.900$

Figure 14.- The effect of elevon deflection on the aerodynamic characteristics of a wing swept back 63° at several Mach numbers, R=2,260,000.



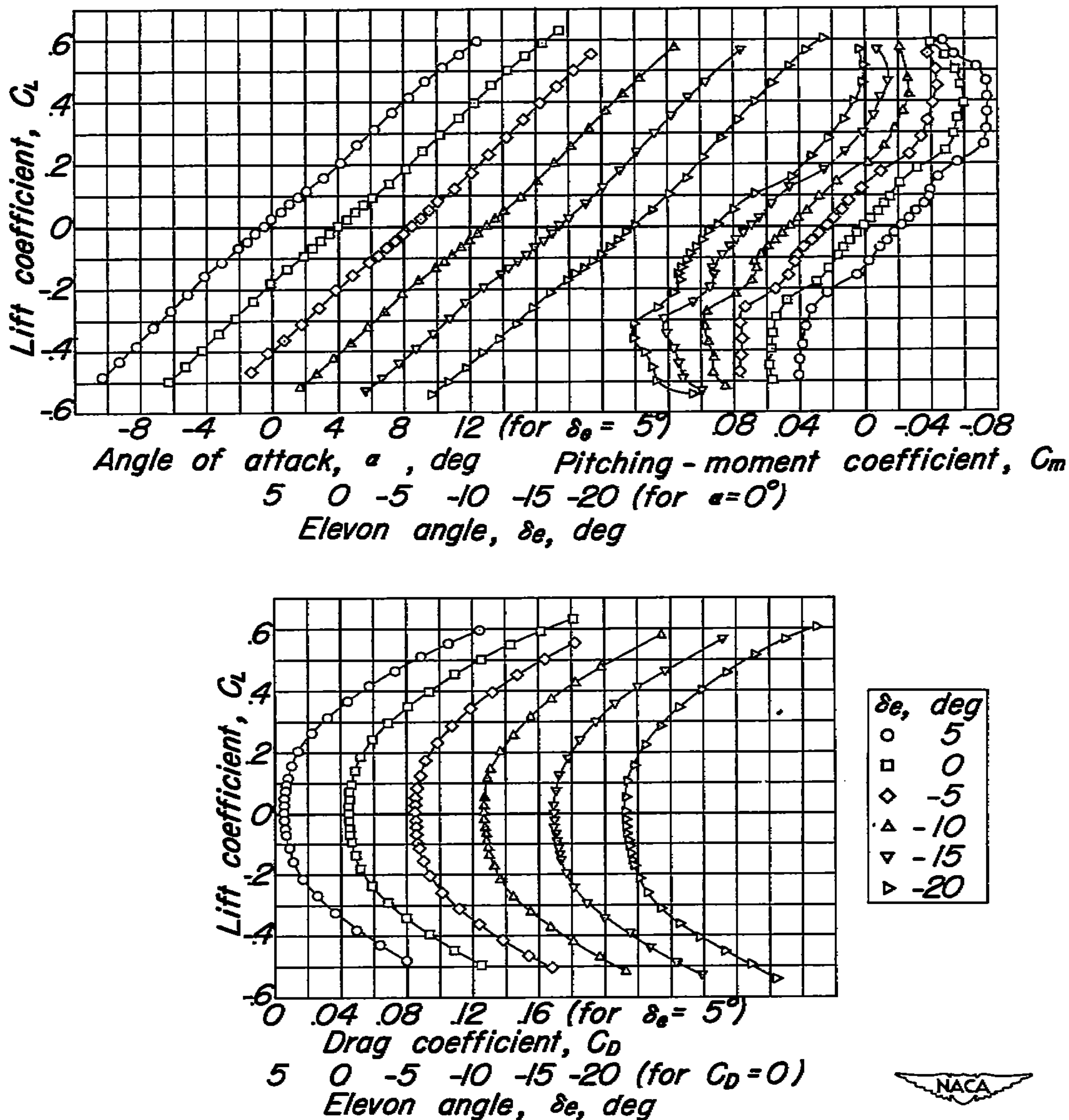
(b) M = 0.875

Figure 14.- Continued.



(c) M = 0.825

Figure 14.- Continued.



(d) M = 0.780

Figure 14.- Continued.

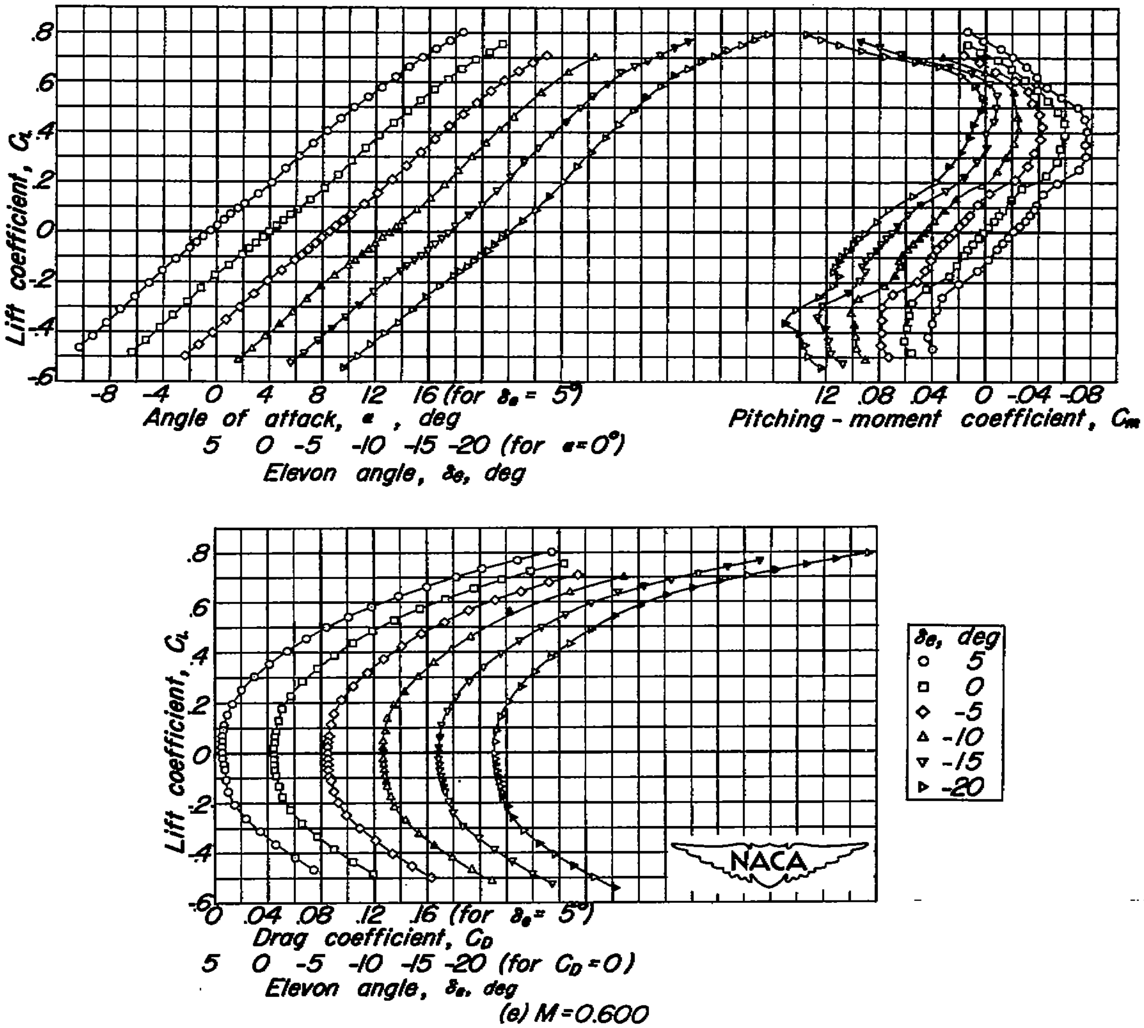


Figure 14.- Concluded.

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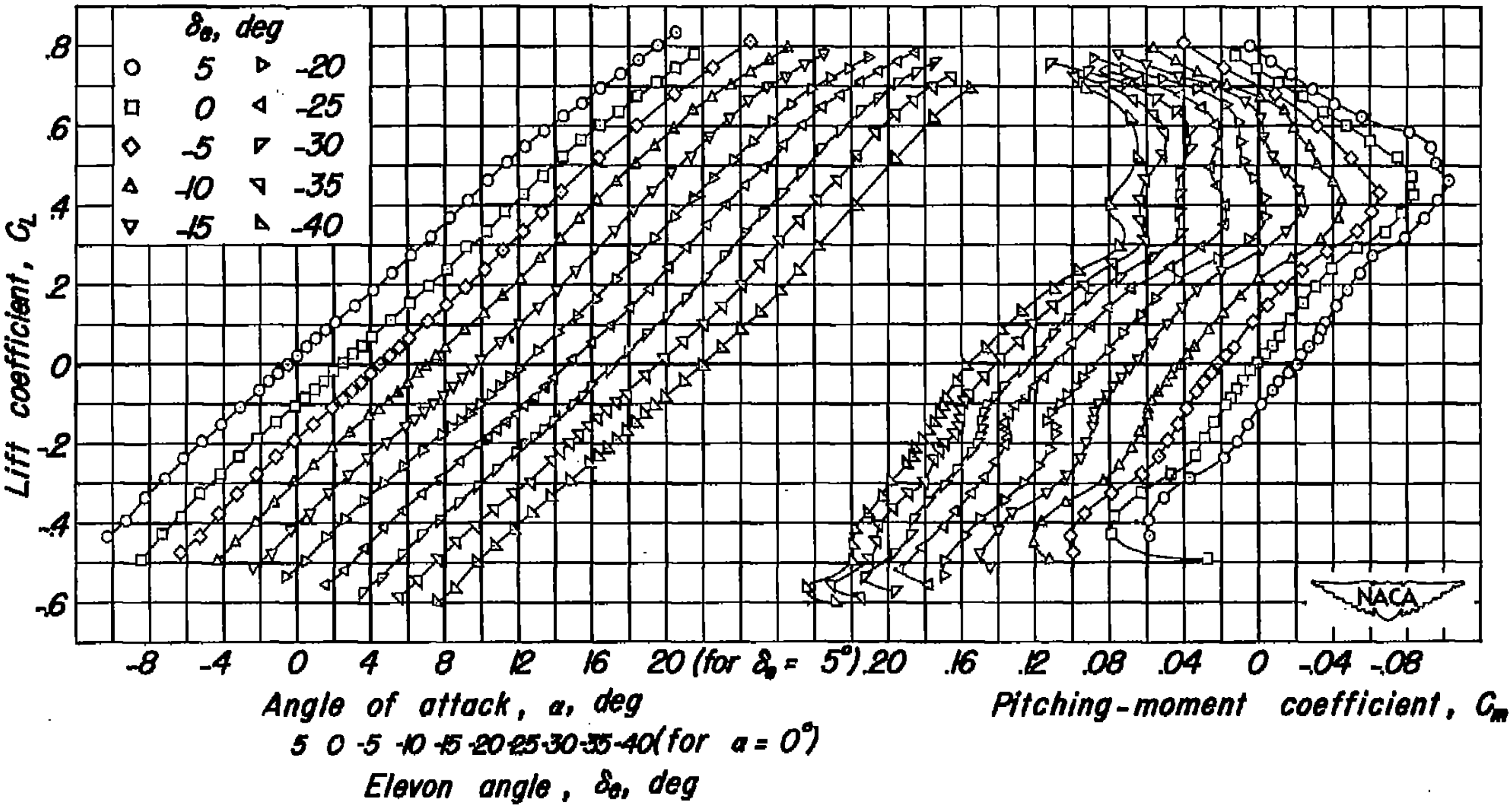
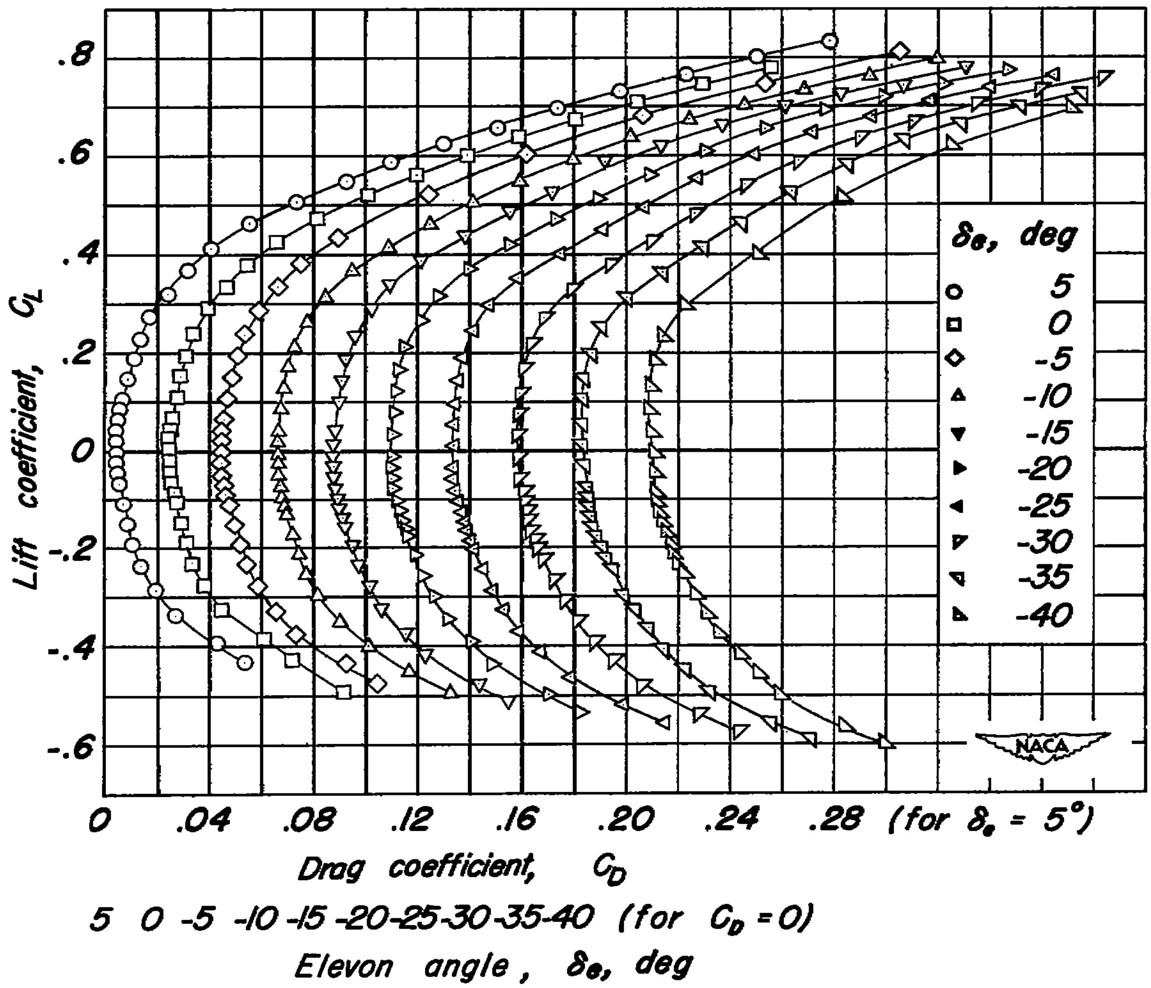


(a) C_L vs α and C_L vs C_m

Figure 15.- The effect of elevon deflection on the aerodynamic characteristics of a wing swept back 63° at a Mach number of 0.19, R = 4,200,000.

[redacted]



(b) C_L vs C_D

Figure 15.- Concluded.

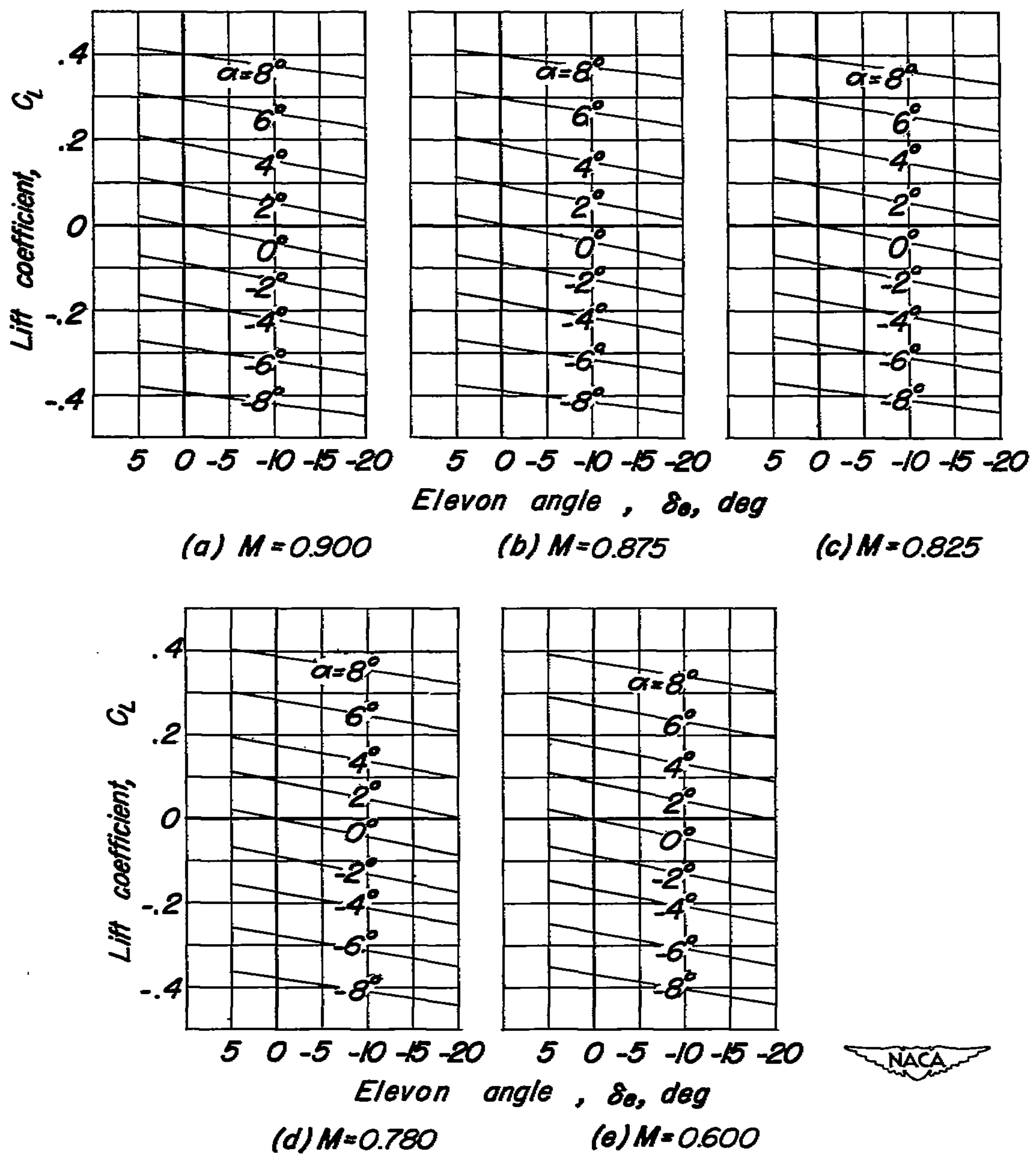
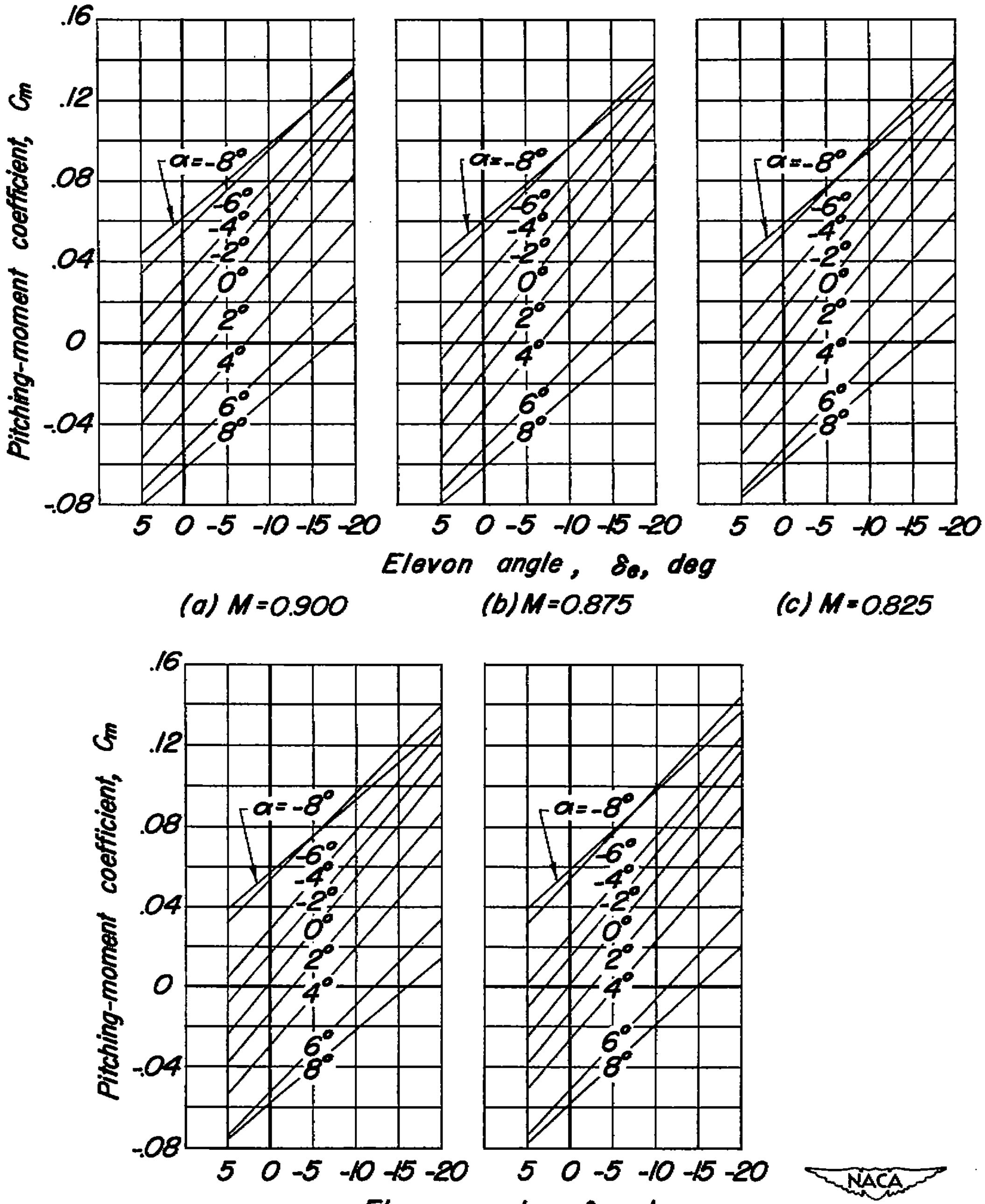


Figure 16.- The variation with elevon deflection of the lift coefficient for a wing swept back 63° at several Mach numbers, R=2,260,000.

[redacted]



(d) M=0.780 (e) M=0.600

Figure 17.- The variation with elevon deflection of the pitching-moment coefficient for a wing swept back 63° at several Mach numbers, R=2,260,000.

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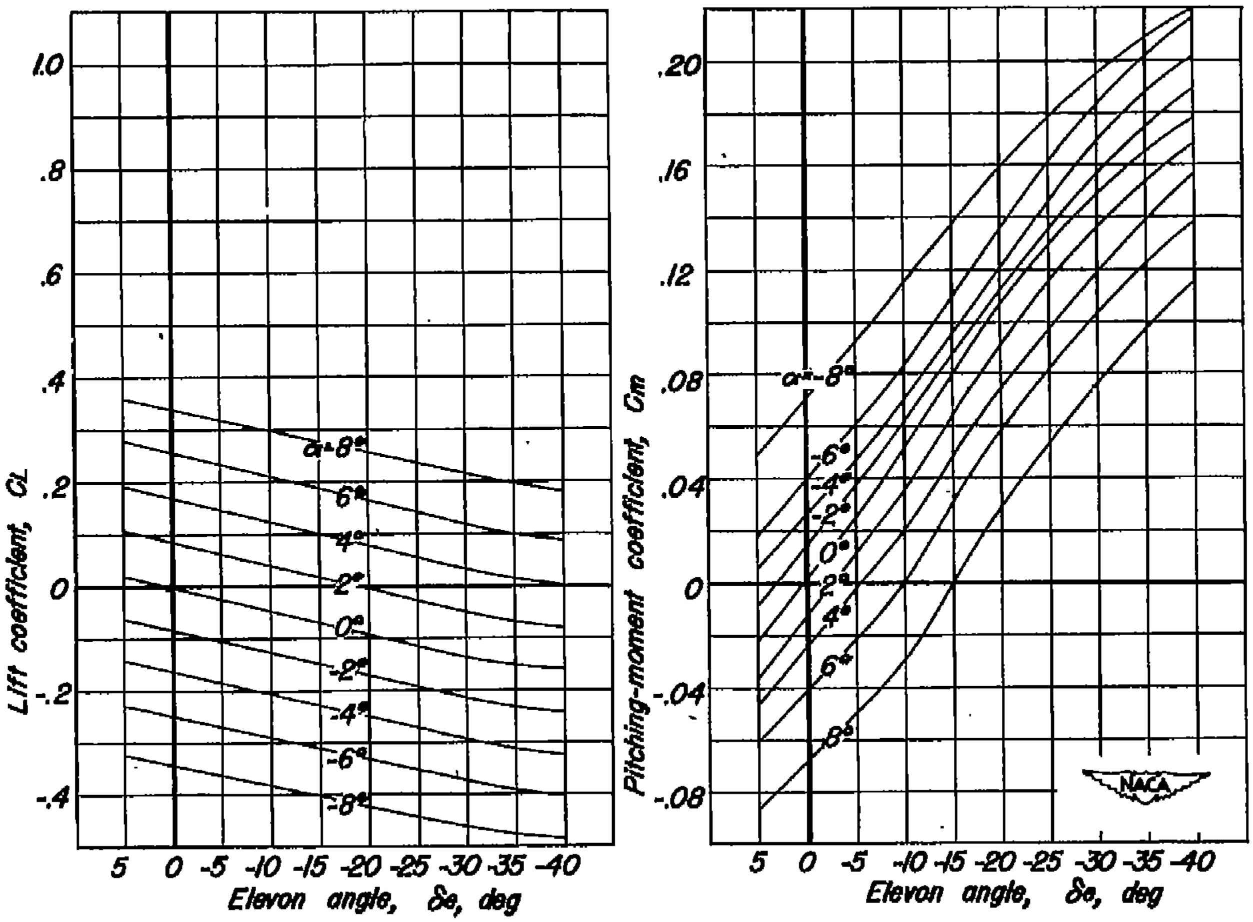


Figure 18 - The variation with elevon deflection of the lift and pitching-moment coefficients for a wing swept back 63° at M=0.19, R=4,200,000.

[redacted]

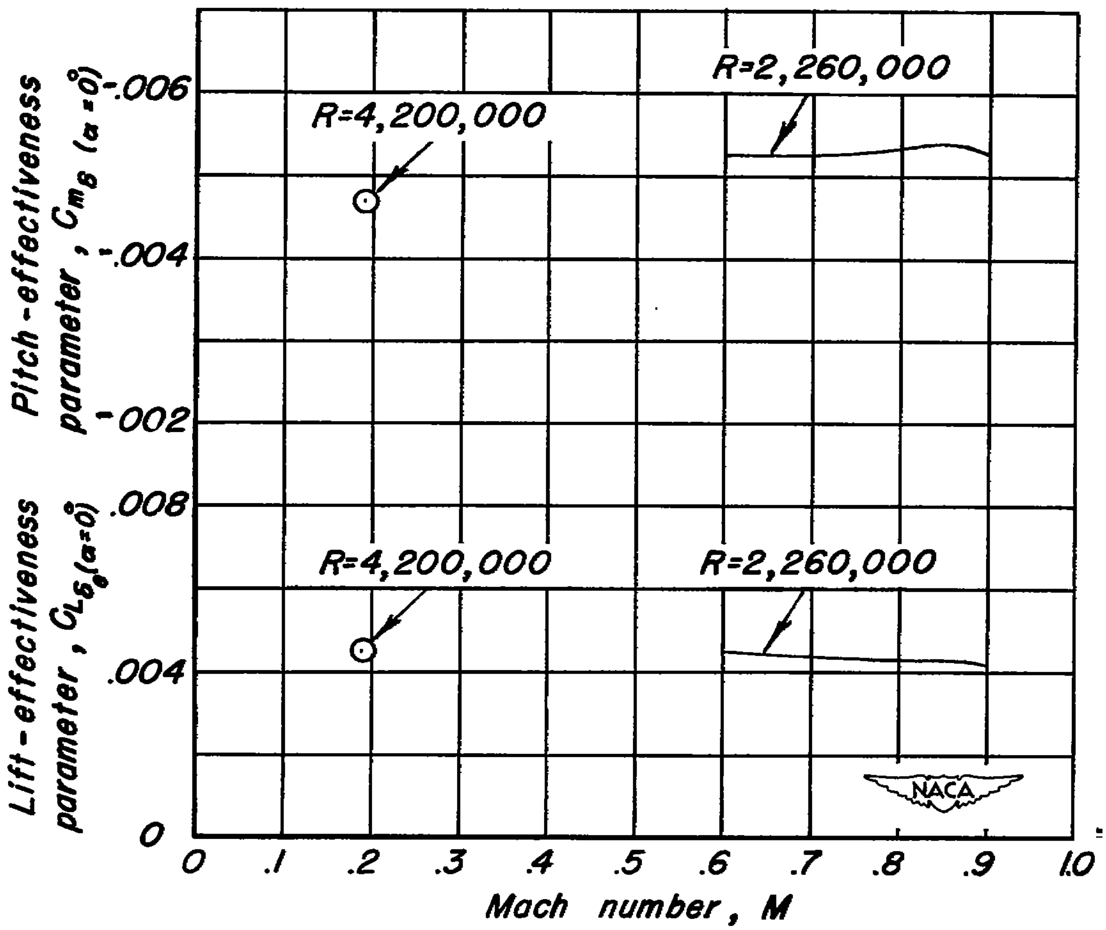
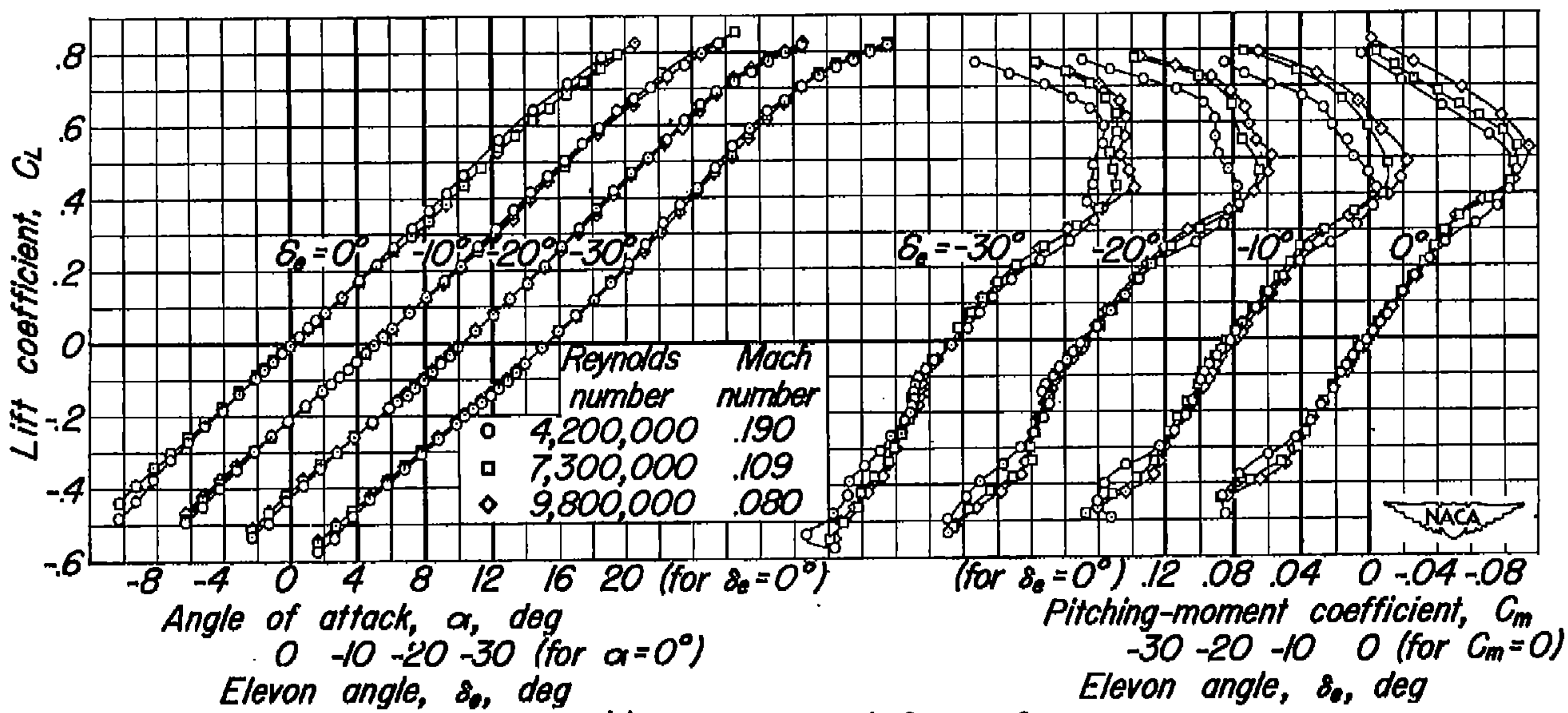
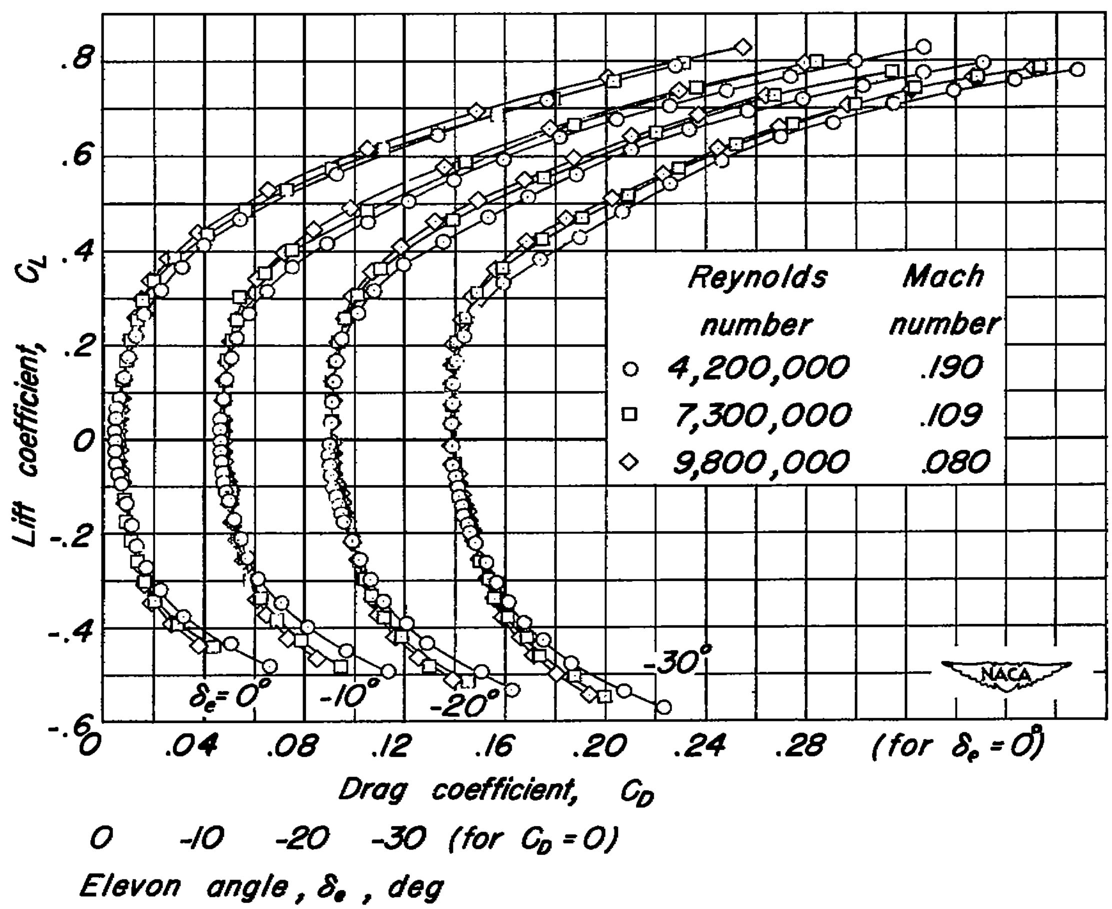


Figure 19.- The variation with Mach number of the lift effectiveness parameter, $C_{L_{\delta_e}}$, and the pitch effectiveness parameter, $C_{m_{\delta_e}}$, for the constant-chord control surface on a wing swept back 63°



(a) C_L vs α and C_L vs C_m

Figure 20.- The effect of Reynolds number on the aerodynamic characteristics of a wing swept back 63° with elevon deflected, q=50 lb/sq ft.



(b) C_L vs C_D

Figure 20.- Concluded.

[redacted]

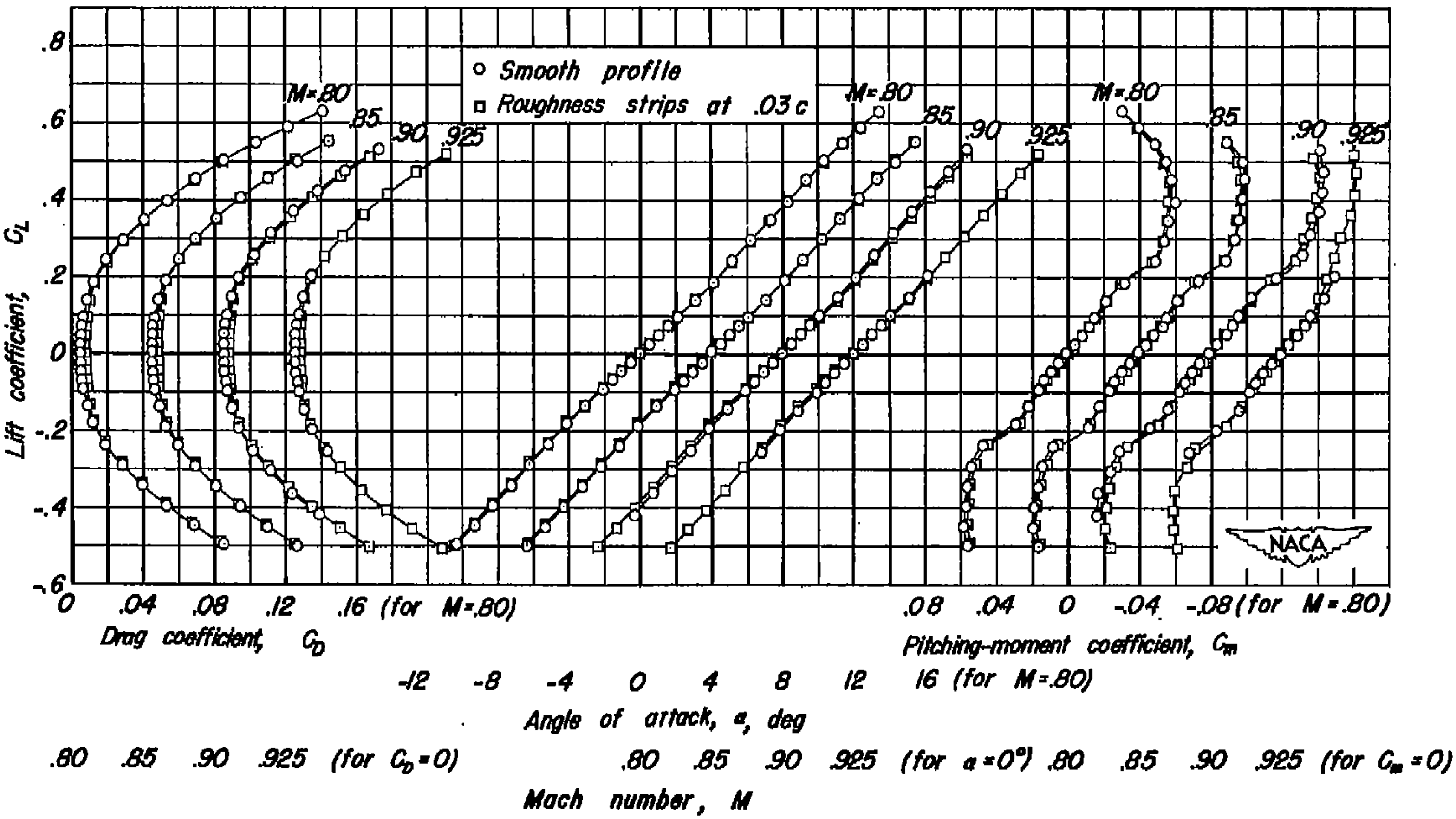


Figure 21 - The effect of roughness strips on the aerodynamic characteristics of a wing swept back 63° at several Mach numbers, R=2,290,000.

[redacted]

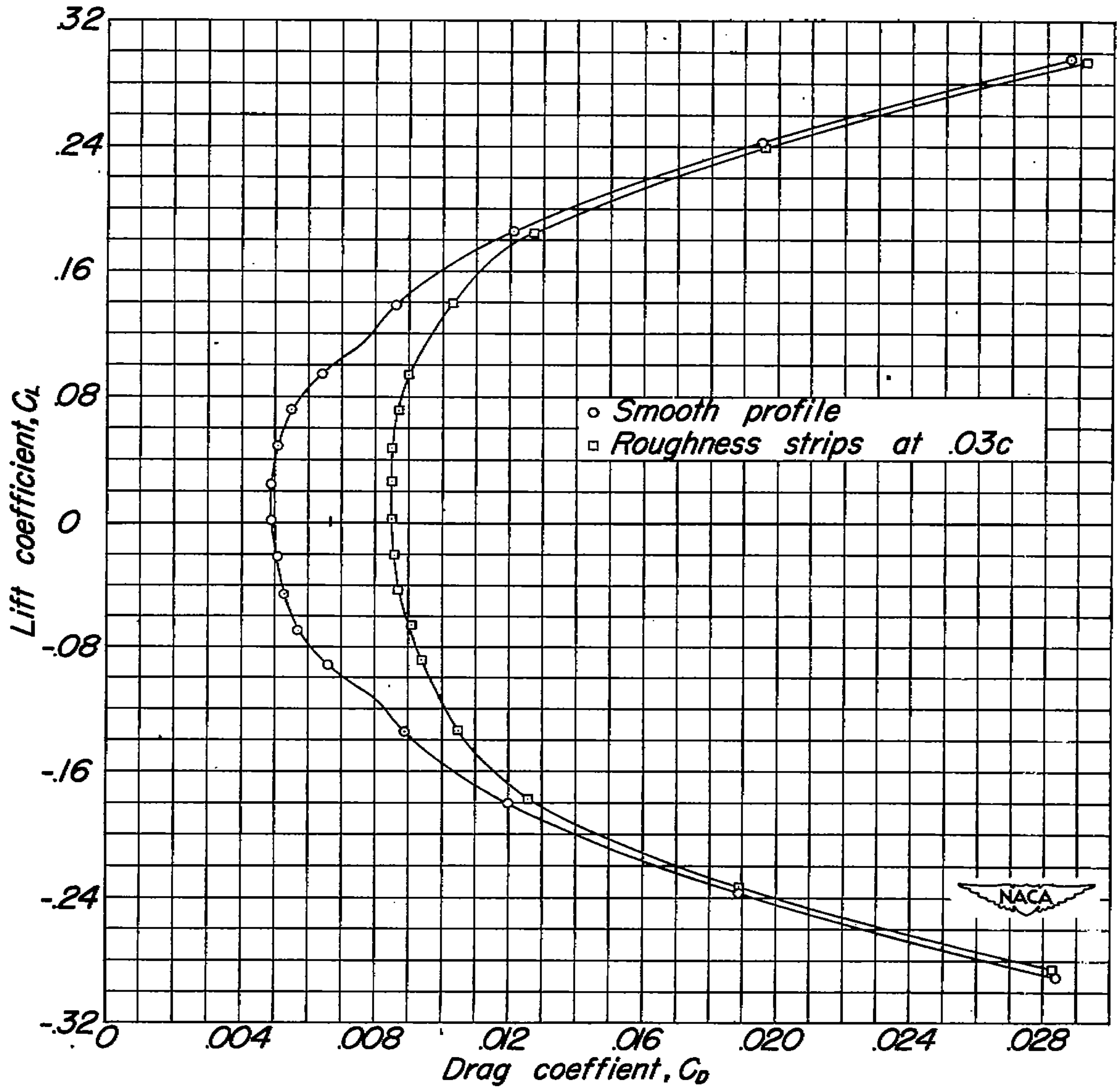


Figure 22.- The effect of roughness strips on the drag coefficient of a wing swept back 63° at a Mach number of 0.80, R=2,290,000.

[redacted]

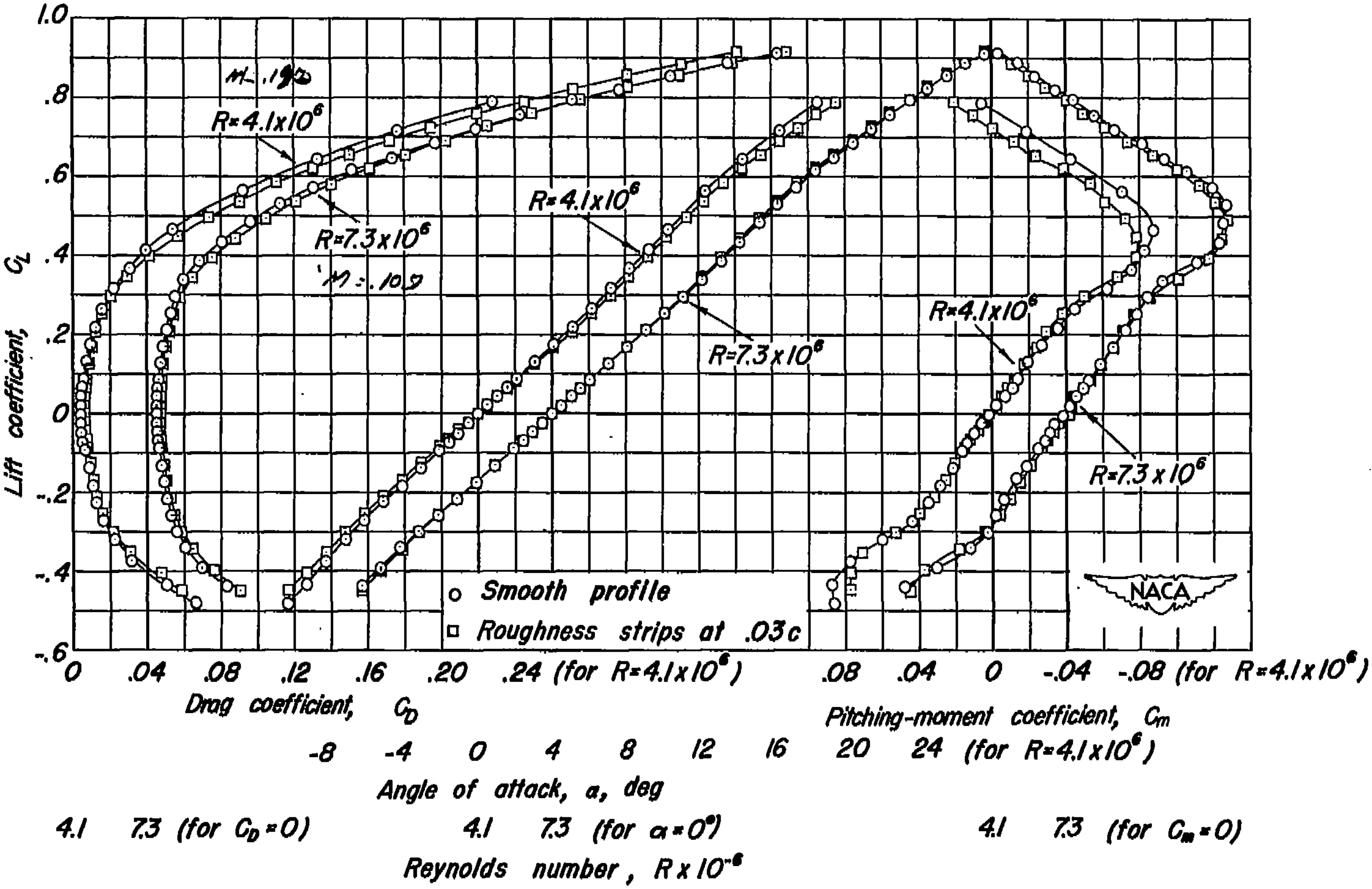
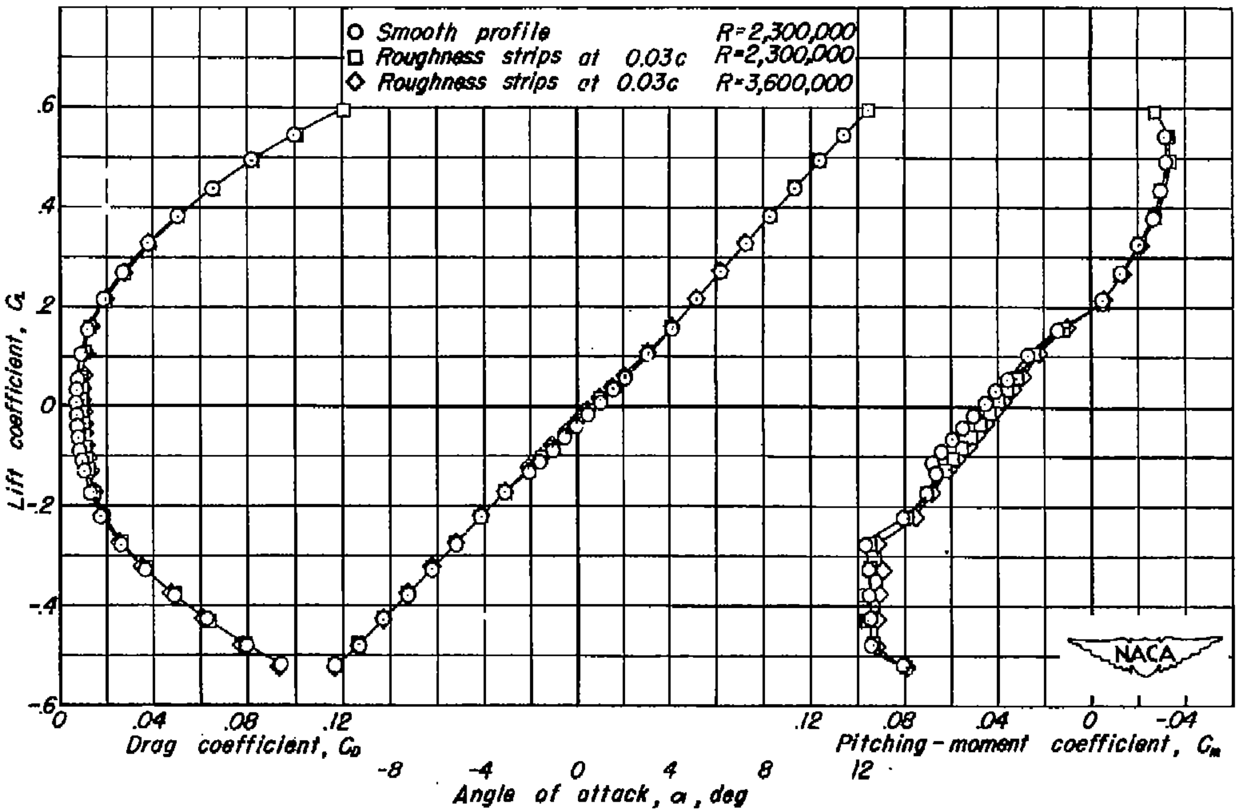


Figure 23.- The effect of roughness strips on the aerodynamic characteristics of a wing swept back 63° at Reynolds numbers of 4,100,000 and 7,300,000, q=50 lb/sq ft.

[redacted]

[redacted]

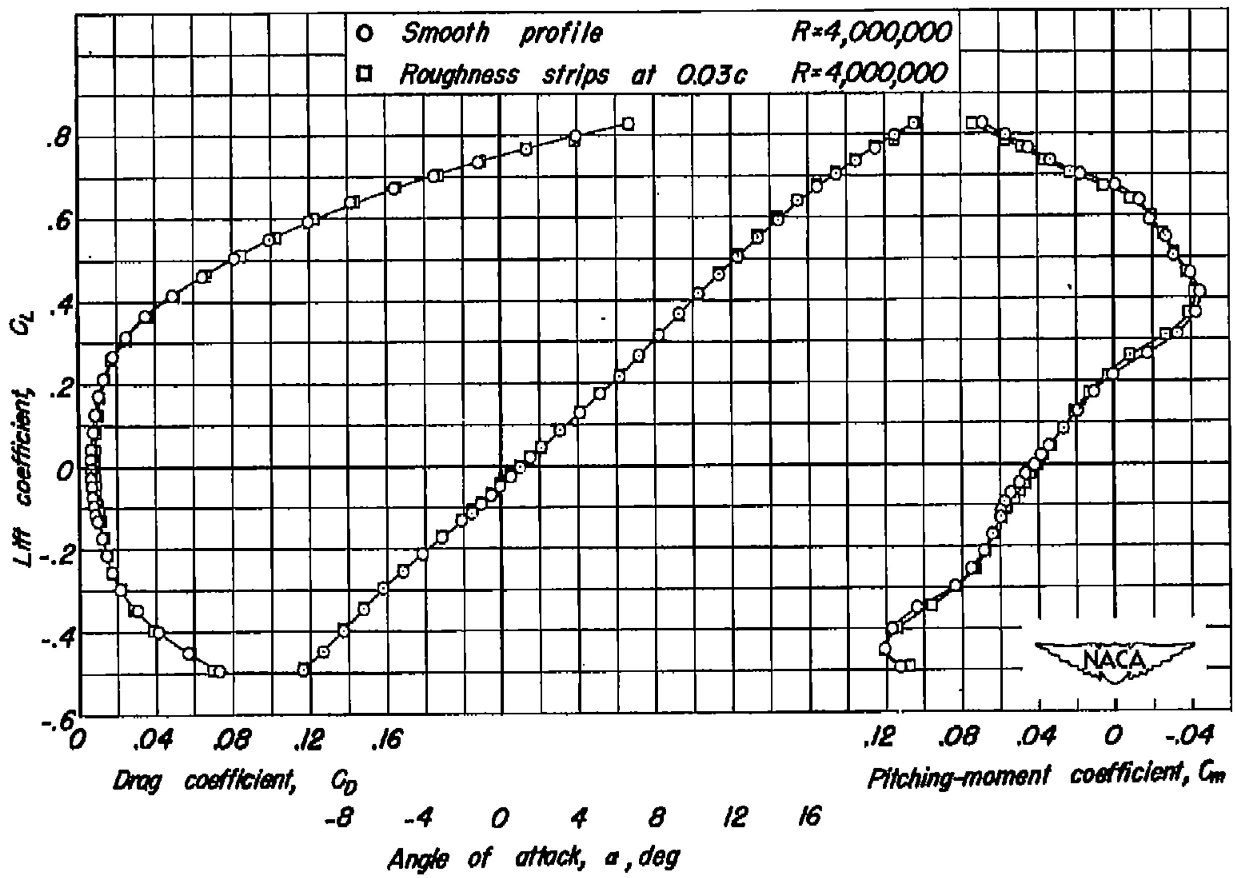


(a) $M = 0.90$

Figure 24.- The effects of roughness strips and Reynolds number on the aerodynamic characteristics of a wing swept back 63° with elevon deflected, $\delta_e = -10°$.

[redacted]

[redacted]



(b) M = 0.19

Figure 24.- Concluded.

[redacted]

[redacted]

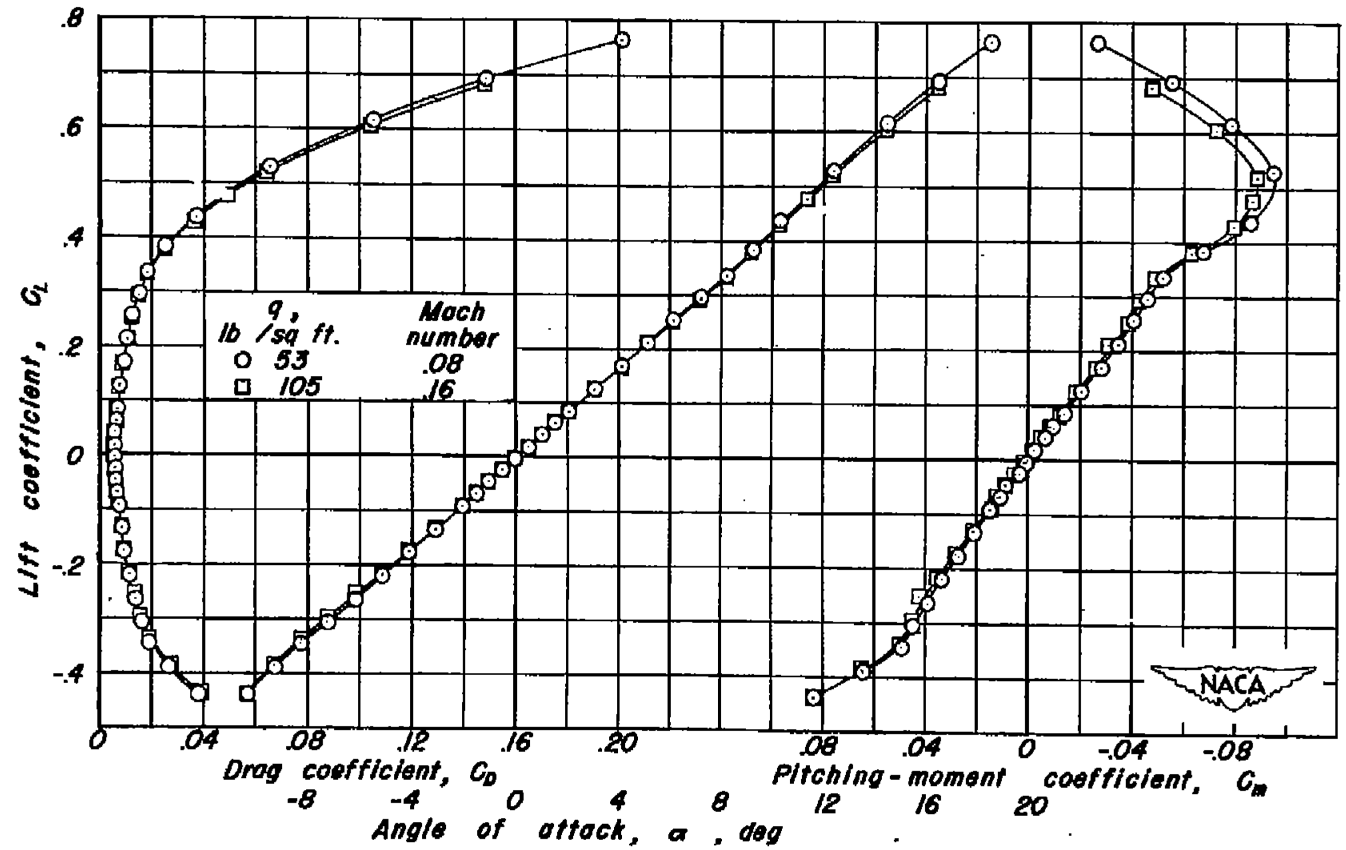


Figure 25.- The effect of bending distortion on the aerodynamic characteristics for a wing swept back 63° at a Reynolds number of 9,750,000.

[redacted]